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WARREN MI L DOWD OCT 84 TACOM-83-33

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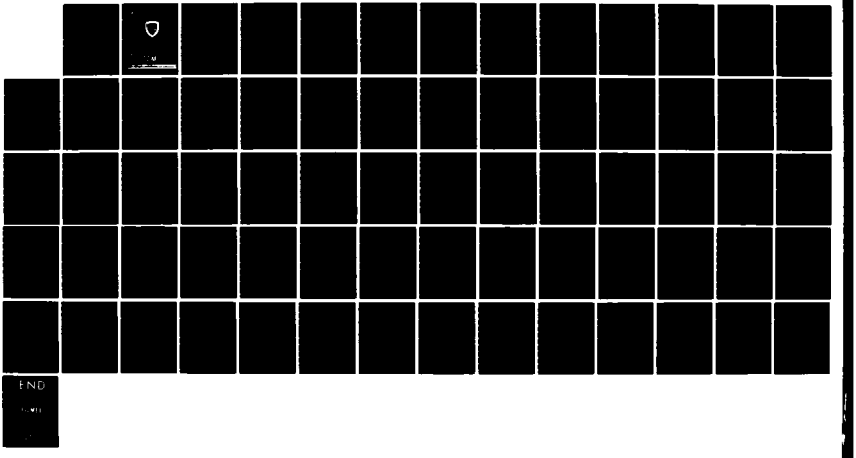

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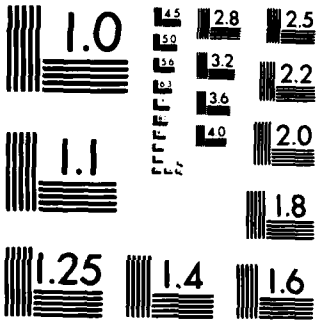
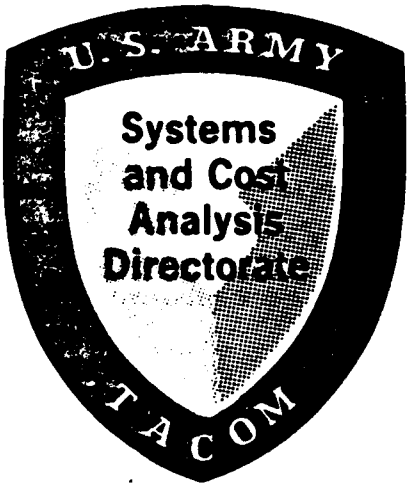


REPORT NUMBER 83-33

M6C NEW VS. OVERHAUL

INTERIM REPORT



OCTOBER 1984

LEE DOWD

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SYSTEMS ANALYSIS DIVISION

U.S. ARMY TANK AUTOMOTIVE COMMAND

SECURITY CLASSIFICATION OF THIS PAGE *(When Data Entered)*

REPORT DOCUMENTATION PAGE

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1. REPORT NUMBER: 83-33	2. GOVT ACCESSION NO. AH49128
3. RECIPIENT'S CATALOG NUMBER	
4. TITLE *(and Subtitle)*: M60 New vs. Overhaul Interim Report	5. TYPE OF REPORT & PERIOD COVERED: Interim Report up to Oct 84
	6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s)	8. CONTRACT OR GRANT NUMBER(s): None
9. PERFORMING ORGANIZATION NAME AND ADDRESS: U.S. Army Tank-Automotive Command, Systems and Cost Analysis Directorate (AMSTA-V), Warren, MI 48090	10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS
11. CONTROLLING OFFICE NAME AND ADDRESS	12. REPORT DATE: October 1984
	13. NUMBER OF PAGES: 64
14. MONITORING AGENCY NAME & ADDRESS *(if different from Controlling Office)*: None	15. SECURITY CLASS. *(of this report)*: Unclassified
	15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT *(of this Report)*

Unlimited distribution

17. DISTRIBUTION STATEMENT *(of the abstract entered in Block 20, if different from Report)*

Unlimited

18. SUPPLEMENTARY NOTES

None

19. KEY WORDS *(Continue on reverse side if necessary and identify by block number)*

reliability, M60, combat tank, SDC, data analysis

20. ABSTRACT *(Continue on reverse side if necessary and identify by block number)*

Sample data collection data on M60 series combat tanks from 6 locations and 2 test sites was analyzed to compare new against depot processed vehicles. Data base is not mature to draw statistically significant conclusions. New appears to be performing better than depot in reliability. Strong base, mileage and age effects are present in the data.

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A1

INTRODUCTION

The initial impetus for this study came from a DA letter questioning whether or not the Army was getting its money's worth from the M60 overhaul program. There were apparently complaints from field units about the reliability of "overhauled" M60's. Here overhaul was apparently used to mean any vehicle that had been through a depot. Tests such as the Basic Armour Reliability Test (BART) also demonstrated a lower level of reliability for overhauled M60's. In addition, what the DA letters were referring to as "overhaul" is closer to what the depots refer to as "rebuild". This is a significantly more extensive and expensive procedure than what the DMWR's define as an overhaul. Further, by far the majority of the vehicles being processed at the depot are not being overhauled, but are being converted and having an inspect and repair procedure performed. It should be pointed out that following the BART, modifications were made to the overhaul DMWR's to correct many of the reliability problems revealed by this test. Thus, the BART data is only of historical interest and should not be used in discussing the reliability of todays M60's.

The DA letter did bring up the question of whether or not "cost saving" procedures implemented at the depot were shifting this cost, or an even greater cost, into the field in terms of lower reliability and increased field repair costs and a related secondary question of how much should be spent at the depot in order to minimize the life cycle maintenance cost to the Army while retaining acceptable reliability.

Data collection is currently in process of M60A3's at three sites; Ft. Stewart, Kirchgoens, and Aberdeen Proving Grounds (APG). Considering the rate at which miles are being accumulated at these sites another 12 to 18 months of data, when combined with data already collected from these and other sites, should prove sufficient for drawing what conclusions can be drawn from the current data base. To get a large increase in the accuracy or significance of the conclusions would require the initiation of SDC at another site or sites and several years of data from each.

OBJECTIVE

The objectives of this study are threefold.

1. To identify whether or not there is a signficant reliability difference between new and depot vehicles. This will be done on the overall vehicle and for subsystems of the vehicle.

2. To attempt to quantify these differences in terms of reliability and cost.

3. To identify areas where procedural changes in the depot process will lower overall cost to the Army and/or improve reliability of M60's.

The purpose of this interim report is to address the first objective. Analysis to date indicates that the data base supporting this study ranges from marginally adequate to inadequate to draw statistically significant conclusions on the reliability of new and depot vehicles. The data base is currently inadequate for statistically significant conclusions to be reached concerning quantification of the reliability and cost differences.

DEFINITIONS

One of the biggest problems this study has surfaced to date is the confusion over exactly what is meant by various terms and phrases. This report will start off with definitions of key terms and phrases used.

Overhaul - This is a set of depot procedures prescribed by Depot Maintenance Work Requests (DMWR) for reconditioning a vehicle (in this case, an M60) that has been certified as needing the same by the Combat Vehicle Evaluation (CVE) criteria. In practice there are modifications to these procedures at the depots due to such things as lack of sufficient parts or improved techniques (i.e. ones that improve the reliability with little cost impact or reduce cost with little or no negative reliability impact). The cost of overhauling an M60 runs between 15% and 25% of a new vehicle. It should be noted that in commercial practice an overhaul may run as much as 80% of the new cost of the vehicle or subsystem.

CVE - A set of criteria based on the condition of the vehicle, which determine whether the vehicle will be overhauled.

Reliability Centered Maintenance (RCM) - An overhaul philosophy that is currently being implemented at Army depots. The basic concept is to automatically overhaul only those components that experience has shown to require it and to test others if possible. If they pass the test, they may be reissued as is.

Rebuild - This is a process that restores the vehicle to the same specifications it met when new. The Army does not rebuild vehicles at this time. It should be noted that this process is very close to what is often referred to commercially as an overhaul.

Inspect and Repair (I&R) - This is the most common depot process now being performed, in conjunction with vehicle conversion, on M60's. It basically consists of fixing anything that is obviously wrong with the vehicle and not doing significant work on parts otherwise.

Conversion - This is a depot process of performing block upgrades on vehicles when sufficient improvements have been made to warrant it. The current M60 conversion program is for the most part converting M60A1's to M60A3's.

Depot Vehicles - This will be used to indicate any vehicles that have been through a depot for any level of maintenance or conversion.

New Vehicles - These are vehicles that have been issued to the units without going through a depot for conversion, overhaul, or I&R.

Scoring - Failures are assigned a numerical score, from 0.00 to 1.00 in steps of .05. These "scores" are assigned according to References 2, 3, 4, and 5. This score reflects the combined probability of the failure being chargeable to the vehicle (and not to human error or other accidental source) and that the failure would further cause the subsystem, of which it is a part, to fail (system criteria) or cause a mission failure (mission criteria).

System Score - The system score of a failure is a number between 0.00 and 1.00 that is a reflection of whether or not that failure was chargeable to the vehicle and what chance it had of causing the subsystem, in which it occured, to fail.

Mission Score - The mission score of a failure is a number between 0.00 and 1.00 that is a reflection of whether the failure was chargeable to the vehicle and what chance that failure had of rendering the vehicle incapable of completing its mission. Mission scores are usually less than or equal to system scores.

Linear Regression - An established mathematical technique to find the best fitting straight line through a set of data points.

METHODOLOGY

Reliability data on M60's is available through two data collection sources; Sample Data Collection (SDC) and testing at APG. The data from these sources are maintained in two separate data bases. The SDC data base is maintained by Control Data Corporation (CDC). It is compiled directly from data sent in by the SDC data collectors. The other data base is maintained by General Dynamics (GD). For their data base, GD periodically extracts data from the SDC data base and data from tests at APG. Based on the data extracted, each incident is scored according to both mission and systems criteria. The scores, the extracted data, and other derived data are then added to their data base.

Scoring is necessary in order to separate nonrelevant failures from those that reflect the reliability of the vehicle. The scoring criteria used by GD is that sited in references 2, 3, 4, and 5. These criteria are a comprehensive set accepted by the M60 and the reliability communities so as to have a common definition of scores and failures. For that reason, the GD data base was the primary one used for this report. The CDC data base was used for data checking and to provide ancillary data not found in the GD data base. The GD definitions of vehicle subsystems were used. They are as follows:

1 - Propulsion
2 - Suspension and Track
3 - Hull
4 - Armament and Firepower
5 - Gun Control
6 - Fire Control
7 - Turret Control
8 - Communications, Survival, Protection, and Ancillary equipment.

Analysis was done on system score, mission score, and the first failure of each vehicle subsystem that caused a system score to be charged against the vehicle. The analysis of first failures was done because this should provide a good measure of the initial reliability differences between new and depot vehicles. Once a significant amount of maintenance has been performed on a vehicle, the measure is not just of new vs depot, but of the quantity and quality of the parts replaced and the maintenance performed.

For the first failure analysis the first failure, which had a non-zero system score, in each vehicle subsystem was recorded. For each site this data was then fitted with a probability distribution that best fit the failure data. In most cases, where a fit was obtained, this was a Weibull although for several, it was exponential. In other cases, there was insufficient data to get a statistically significant fit to a distribution. The latter includes all subsystems on the depot vehicles at APG. Confidence limits were then calculated about the means and the means were compared with these to determine if there were any significant differences. Distribution parameters, means, and confidence limits appear in Appendix I.

A sample plot of a two parameter Weibull distribution is shown in Figure A. The two parameters alpha and beta, here referred to as a and b, are for an equation of the form:

$$F(x) = 1 - \exp(-(x/a)^b)$$

An exponential can be viewed as a degenerate form of the Weibull where beta is equal to 1. The Weibull distribution is well accepted for representing reliability distributions.

For analysis of system and mission scores, the data was grouped into 100 mile increments and normalized by the number of vehicles in each location and treatment (new or depot) in that mileage group. This was performed for all subsystems and the overall vehicle. The normalization was performed in order to allow data to be studied on a per vehicle (reliability vs test miles) basis. The measure of reliability degradation with accumulated test miles is very important in determining the overall long term reliability

THE FAILURE DENSITY FUNCTION FOR THE WEIBULL DISTRIBUTION. ALPHA = 1., GAMMA = 0.

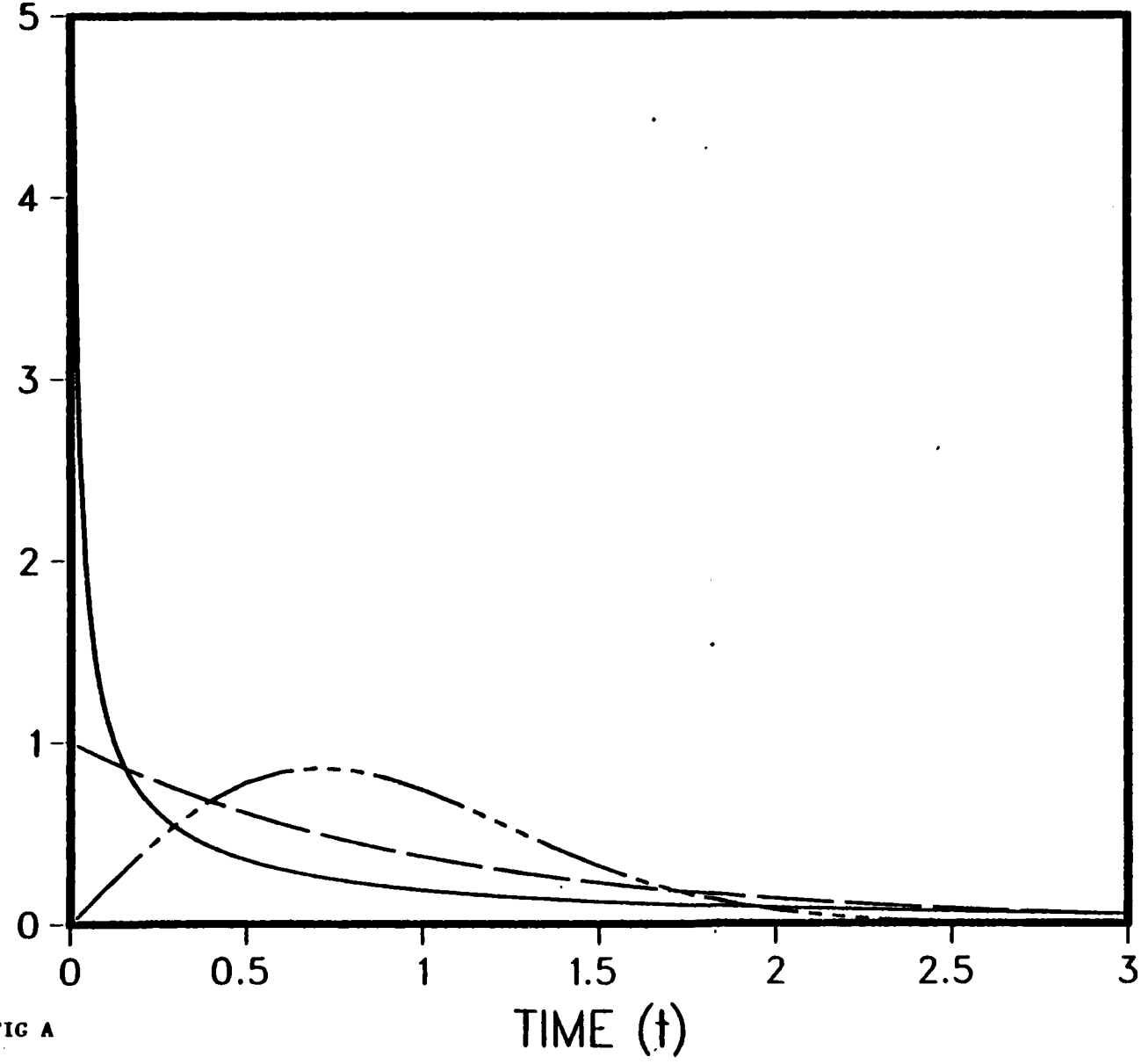
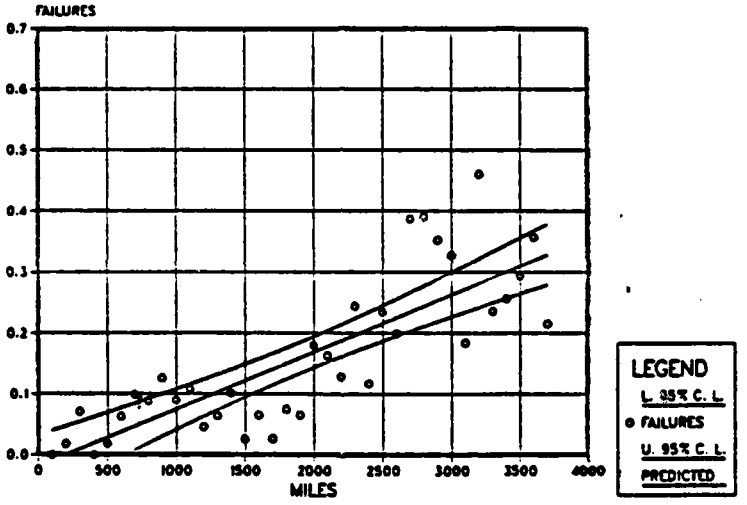


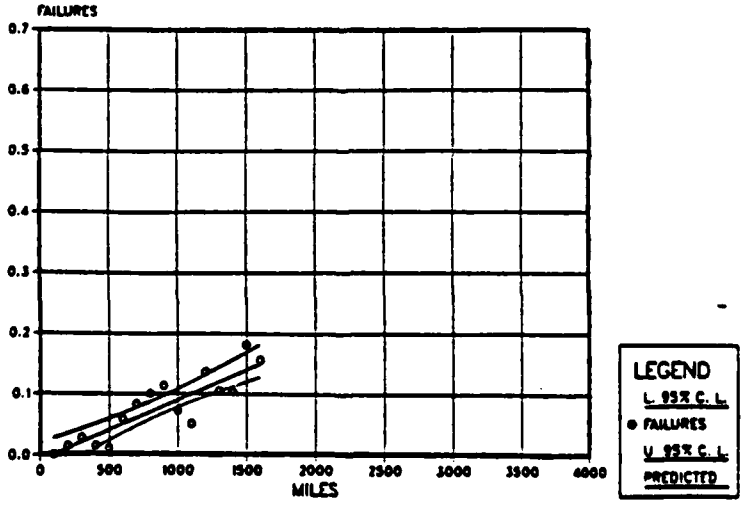
FIG A

and cost differences between the new and depot vehicles. Regression lines and 95% confidence bands along with scatter plots of the scored failures per hundred miles vs miles were then produced for each site, treatment, subsystem and overall score, and both system and mission score criteria. Two sample scatter plots follow. In addition, Appendix 2 contains the scatter plots of the system scores overall vehicle. In all of the scatter plots, the x axis is test miles and the y axis is scored failures per vehicle per hundred miles. Due to the limited data from most sites, only linear regression lines were calculated at this time (it does appear that for some systems and locations the best fit may be with a nonlinear curve). Analysis was then performed to see if a mileage dependency could be supported for each subsystem, site, and treatment.

FAILURES PER MILE BA_S.1



FAILURES PER MILE FR_S.1



Analysis for inclusion in future reports still will include, but not be limited to the following:

1. Analysis of the effect of the rate at which test miles are accumulated on reliability.

2. First failure analysis below the subsystem level for some major components.

3. Use of the data from all of the vehicles at Ft. Polk for comparison of age vs reliability.

4. Analysis of reliability vs rounds fired.

5. Analysis of data of manufacture or depot treatment vs reliability.

6. Analysis of cost vs score.

Many of these analysis are aimed at quantifying biases such as vehicle age, mileage rate, base, etc.

DESCRIPTION OF DATA

The data used in this report was collected under Sample Data Collection (SDC) at Bamberg, Freiberg, Weisbaden, Kirchgoens, Ft. Stewart, and Ft. Polk; and during comparison testing at Aberdeen Proving Grounds (APG). The SDC data is input into the SDC data base currently maintained by CDC. Data from the SDC data base along with the data from testing at APG, is reduced and scored by General Dynamics Corporation (GD), then inserted into their data base. The scoring on SDC data prior to December 83 has been checked by an official scoring conference. APG data and SDC data collected after December 83 has been scored by GD only. Based on the results of the last official scoring conference, held in February 1984, it was judged that any biases introduced by using the data with only GD scoring are not significant compared to the benefits of using this data.

DESCRIPTION OF DATA BY SITE

Aberdeen Proving Ground (APG) - Both new and depot vehicles are being tested at APG. Until recently, all vehicles were run in excess of 2000 miles. For more recent tests, this has been increased to 4000 miles. These miles are put on the vehicles in approximately six months by APG personnel, resulting in a usage pattern quite different from that of field units. Another biassing factor is the time when vehicles are tested. A new vehicle now under test was probably manufactured about six months ago. While some of the previous vehicles were manufactured several years ago. During this time, changes have been made in the manufacturing process which may have significant effects on reliability. The number of vehicles tested is also quite small. At this point, 11 new and 6 depot vehicles have been tested. This is not a sufficient number of vehicles to produce enough scored mission or system failures for

the statistical test used for the first failure analysis to produce meaningful results. The low number of new and depot vehicles results in a great deal of uncertainty in the analysis of scored failures.

Bamberg - 55 new vehicles were under SDC at Bamberg. This site has the most complete data of any sites with only four vehicles having under 2000 miles and eight with over 3700 miles. The vehicles at this site are getting more miles per year than any of the other SDC sites. SDC on M60A3's was terminated at this site this summer as the unit there has been re-equipped with M1's.

Freiberg - Over 100 new vehicles were under SDC at Freiberg. Most of these vehicles have over 1000 miles. Five have over 1700 and none over 2000. The number of vehicles at this site is more than adequate. However, the test miles on the vehicles at Freiberg is only marginally adequate for our purpose.

Kirchgoens - 59 vehicles are or have been under SDC at Kirchgoens. Of these, 17 are new and 42 depot (Mainz) vehicles. The new vehicles have averaged about 920 miles with 8 over 1100 miles. The depot vehicles have averaged about 1160 miles with 4 over 1400. This site contains the only mixed site of new and depot vehicles thus making it very useful for comparison purposes. It is also the only site with vehicles that have been through the Mainz depot. While the sample size of the new vehicles is adequate, and the sample size for the depot vehicles is good, the test miles to date are not really adequate for the purposes of this study. SDC on M60A3's is still active at this site.

Ft. Polk - 45 M60A1 RISE Passive vehicles originally planned to compare the regular overhaul techniques to an RCM approach and an I&R approach are part of the data base. All of these vehicles have been through Anniston Army Depot. All but 2 of these vehicles have completed 1000 miles and 7 are over 1800 miles. In addition, there are over 100 other M60A1's that were under SDC at Ft. Polk. These have not been scored and are not in the GD data base, and thus were not used in this report. SDC has been terminated at this site as of this year.

Ft. Stewart - 59 M60A3's which have been processed through Anniston Army Depot are or have been under SDC at Ft. Stewart. Most of these vehicles have over 1000 miles and 4 have over 1800, thus the test miles are just getting into the acceptable region for our purposes. SDC continuing at this site on M60A3's.

Weisbaden - 56 new M60A3's were under SDC at Weisbaden. All of these vehicles have under 1000 miles, thus greatly limiting the utility of this site for the purpose of this report. SDC has been terminated at this site.

The table below summarizes the data available from the various sites used.

Data Status Table

Location	Status	Quantity	Ave Miles	Miles /year	Date of Treatment [1]	Max Miles [2]
Bamberg	New	56	3200	1120	79-80	5373
Freiberg	New	110	1200	1060	78-81	1911
Kirchgoens	Depot	42	1200	960	81-82	1622
Kirchgoens	New	17	930	910	79-80	1501
Weisbaden	New	56	710	800	79	958
Ft. Stewart	Depot	59	1300	980	82	1862
APG	Depot	6	2800	*	**	3897
APG	New	11	2500	*	**	4197
Ft. Polk	Depot	45	1500	750	81	3641

1 Date of treatment - is the year of manufacture for new vehicles and the year of depot processing for depot vehicles.

2 Max miles - is the maximum test miles on any vehicle at that location and treatment. The Ft. Polk value is somewhat suspicious as the vehicle with the next highest test miles has only 1925.

* - As the test at APG take less than a year, this leads to a very high and not very meaningful number for yearly mileage.

** - Vehicles tested at APG are taken off the appropriate line one a time and thus are run from the start of testing to date.

SOURCES OF ERROR AND BIAS

There are two major sources of possible error in the data at this time. One is insufficient data, either not enough miles or not enough vehicles, at most sites. As long as SDC and APG testing continues on the M60 vehicles the probable errors from these sources will decrease. Since most of the vehicles at Kirchgoens and Ft. Stewart are in the 1000 to 2000 mile range, improvement in this area should be significant over the next 12 to 18 month period. Each additional vehicle tested at Aberdeen also greatly improves the statistical confidence in that data. The other major problem is that only two sites have more than one type of vehicle. That is:

1. Kirchgoens has new vehicles and depot vehicles from Mainz.

2. APG has tested new vehicles and depot vehicles from Anniston.

3. There are no depot vehicles from Anniston in Europe under SDC.

4. There are no depot vehicles from Mainz under SDC except at Kirchgoens.

5. There are no new M60A3's under SDC in CONUS.

This means that it will be possible to determine reliability differences between the various sites. However, separating out the new vehicle vs depot vehicle effect from the other effects will be difficult if not impossible.

Other sources of error and bias include:

1. The nonrandom nature of the sample - All the vehicles in 6 units are or were under SDC. This is not a good random sample of the entire M60 fleet. Even limiting discussion to the M60A3, these vehicles are operated in an extremely wide variety of locations, climates, and usage conditions. Data collection on a truly random sample is prohibitive due to cost and administrative considerations. Because of this, errors will be introduced whenever the data or conclusions based on it are extrapolated to include the entire M60 or even M60A3 fleet.

2. Variations in data collection with time or location - What and how data was recorded may vary somewhat from one site to the next or even within a site. This is especially likely when comparing early SDC data to later SDC data and comparing SDC data to APG data.

3. Variations due to vehicle treatment - There are a number of factors in this category of varying levels of significance. Perhaps the most significant is the variation in policy, quantity, and quality of maintenance. This will vary to some extent from crew to crew but can show an extremely wide variation from unit to unit. Motivation of crew and maintenance personnel can be a large factor here. Other factors included in this category are climate, terrain, and type of usage.

4. Usage variations - The main measure here is how fast miles are accumulated on a vehicle. Within a unit, the mileage rates usually vary by about a factor of 2 between extremes. At different locations the mileage rate varies by less than a factor of 1.5 except at APG, where it is a factor of 4 or more than at the SDC sites. The four extremes of this type of usage variation are: The "Hanger Queen", a vehicle that is in the shop so much for maintenance that it accumulates little or no mileage. Similarly, a vehicle may be "saved" for special purposes being given a great deal of preventive maintenance (PM) with very few miles accumulated. A third type is the "runner", a vehicle that requires very little unscheduled maintenance and is getting a lot of use. The runner can be due to an exceptional vehicle, good PM, a good crew, or more likely some combination of these. The fourth extreme is a vehicle that is being used so much that it gets little or no PM and receives maintenance only when it is required (something major breaks) which becomes more and more common as miles accumulate.

5. Date of manufacture or depot processing - The date of manufacture may well play a very important role in reliability as most of the Engineering Change Proposals (ECP's) over the last few years have been reliability oriented. It can also be a factor in depot processing as the date of processing will effect what ECP's are implemented. There are also occasional defective parts or a lack of parts supplied to the depot which will affect the reliability of vehicles processed during those times. In addition, depot processes are not a completely static thing and changes with time may improve or decrease reliability.

6. Data collection and reduction errors - These can occur at all stages including initial collection, entry into the SDC data base, transcription and reduction into the GD data base, and transcription and reduction for use in this report. A number of lessons have been learned in this regard and current procedures have greatly reduced the frequency of these errors. Thus, the data we are most dependent on, that from Bamberg, Kirchgoens, and Ft. Stewart, is thought to be reasonably consistent and free of errors.

INITIAL RESULTS

This section is divided into 2 parts. The first is the results of the first failure analysis. The second contains the results of the anlaysis of the system and mission scores.

1. First Failure results

The tables below detail the results of the anlaysis of first system scoreable failure in each vehicle and system. It will be noted that there is currently insufficient data on a number of systems at some locations to make any comparison.

The following conventions are used in the tables below. A "+" indicates that the mean mileage at first failure in vehicles at the location to the left was significantly greater than that of vehicles in the location above. A "-" indicates a lower mean mileage at first failure in the location to the left than in the one above. An "=" indicates that no statistically significant variations were present either because the means were nearly equal or the confidence limits at one or both locations are very broad. All means are the means of the fitted distribution calculated from the data and are not the average of the data values.

First Failure Tables

Propulsion System

Location	Status	Abrv	Mean	Ba	Fr	We	KD	St	Po
Bamberg	New	Ba	1210	=	+	+	+	+	+
Freiberg	New	Fr	730	-	=	+	+	+	+
Weisbaden	New	We	290	-	-	=	-	-	=
Kirchgoens	Depot	KD	620	-	-	+	=	+	+
Ft. Stewart	Depot	St	460	-	-	+	-	=	=
Ft. Polk	Depot	Po	360	-	-	=	-	=	=

Suspension and Track

Location	Status	Abrv	Mean	Ba	Fr	We	KD	AN	Po
Bamberg	New	Ba	900	=	+	+	+	+	+
Freiberg	New	Fr	650	-	=	+	=	=	+
Weisbaden	New	We	350	-	-	=	-	=	-
Kirchgoens	Depot	KD	640	-	=	+	=	=	+
Aberdeen	New	AN	620	-	=	=	=	=	=
Ft. Polk	Depot	Po	570	-	-	+	-	=	=

Hull System

Location	Status	Abrv	Mean	Ba	Fr	We	KN	KD	St	An	Po
Bamberg	New	Ba	950	=	+	+	+	+	+	=	+
Freiberg	New	Fr	570	-	=	+	+	+	=	=	=
Weisbaden	New	WE	210	-	-	=	-	-	-	-	-
Kirchgoens	New	KN	420	-	-	+	=	-	=	=	=
Kirchgoens	Depot	KD	570	-	-	+	+	=	=	=	=
Ft. Stewart	Depot	St	520	-	=	+	=	=	=	=	=
Aberdeen	New	AN	760	=	=	+	=	=	=	=	=
Ft. Polk	Depot	Po	520	-	=	+	=	=	=	=	=

Armament and Firepower

Location	Status	Abrv	Mean	Ba	We	St
Bamberg	New	Ba	1425	=	+	+
Weisbaden	New	We	280	-	=	-
Ft. Stewart	Depot	St	570	-	+	=

Gun Control

Location	Status	Abrv	Mean	Fr	We	KD	St
Freiberg	New	Fr	650	=	+	+	=
Weisbaden	New	We	200	-	=	-	-
Kirchgoens	Depot	KD	550	-	+	=	=
Ft. Stewart	Depot	St	630	=	+	=	=

Fire Control

Location	Status	Abrv	Mean	Ba	Fr	We	KD	St	AN	Po
Bamberg	New	Ba	760	=	+	+	+	+	=	=
Freiberg	New	Fr	510	-	=	+	+	=	=	=
Weisbaden	New	We	170	-	-	=	-	-	=	-
Kirchgoens	Depot	KD	470	-	-	+	=	=	=	=
Ft. Stewart	Depot	St	470	-	=	+	=	=	=	=
Aberdeen	New	An	450	=	=	=	=	=	=	=
Ft. Polk	Depot	Po	500	=	=	+	=	=	=	=

Turret Control

Location	Status	Abrv	Mean	Ba	Fr	KD	Po
Bamberg	New	Ba	1650	=	+	+	+
Freiberg	New	Fr	660	-	=	+	=
Kirchgoens	Depot	KD	550	-	-	=	=
Ft. Polk	Depot	Po	650	-	=	=	=

Communications, Survival, Protection, and Ancillary

Location	Status	Abrv	Mean	We	St	Po
Weisbaden	New	WE	280	=	=	=
Ft. Stewart	Depot	St	590	=	=	=
Ft. Polk	Depot	Po	450	=	=	=

At this time, little can safely be concluded about the effect of depot treatment of M60's on MMBF vs new vehicles. For example, the new vehicles at Bamberg are equal or superior to the vehicles at all other locations for the systems for which it has sufficient data while Weisbaden, which also has new vehicles, has a lower or equal mean mileage at first failure to all locations to which it can be compared. The main reason for the lack of ability to separate the failure rates at various locations is the lack of data. As more data becomes available, it will be possible to derive distributions for those locations for which it was not possible at this time. In addition, the confidence limits should narrow significantly for those locations for which distributions were derived. This will significantly increase the ability to distinguish between various locations.

It is worth examining the case of Bamberg in a little more detail to illustrate a few points. As was pointed out above, the mean miles to first failure is either significantly higher or comparable to all other locations for all subsystems for which it may be compared. They also have the highest miles per vehicle, and highest mileage rate. They are reputed to have a very strong maintenance policy and highly motivated personnel. Many of these miles are put in a border patrol mission which probably has a different profile from the missions at other locations. All of these can be very significant factors in addition to being new vehicles. At this time, it is not possible to separate out these biasing factors.

2. System and Mission score results

This section contains the results based on the mean miles between failures (MMBF) and the regression parameters. Following the discussion part of this section there are two sets of tables. The first set contains 4 tables detailing the MMBF for both system and mission criteria failure scores for overall test miles and for the first thousand miles of vehicle operation. The second set indicates which subsystem and which locations a mileage dependency for the failure rate has been established. For more details on this dependency the regression line, 95% confidence limits, and data points are shown on plots in Appendix 2.

With the current data, it is possible to make some comparisons of the reliability of the M60's at various locations. However, for comparing the "life time" reliability costs of New vs Depot M60's the data is inadequate. As the following tables demonstrate, the mileage effect is very strong for the overall MMBF using the system failure criteria. A study of the tables will show that even locations where the vehicles have not traveled much over 1000 miles there are some significant variations between the 1000 mile MMBF and the overall MMBF for the same criteria. On most systems at Bamberg, the differences are more dramatic. When the depot vehicles at Ft. Stewart and Kirchgoens and the new vehicles at Kirchgoens have mileage comparable to that at Bamberg, it will be possible to obtain meaningful measures of overall reliability and cost for new and depot vehicles.

To illustrate the difference in MMBF at each location for first 1000 and all accumulated mileage, bar charts are included over all mission failures (Figure 1) overall system failures (Figure 2) Hull only (Figure 3), Propulsion (Figure 4), Fire control (Figure 5) and Suspension and Track (Figure 6). The x axis nomenclature on each of these six figures reads base (miles) in accordance with the following tables. It can be concluded that at Bamberg and other locations, there are large discrepencies in the measured MMBF at 1000 miles and all miles up to base maximum. This means that extrapolating data to an overall MMBF from any trend analysis could prove erroneous.

OVERALL – MISSION CRITERIA MMBF

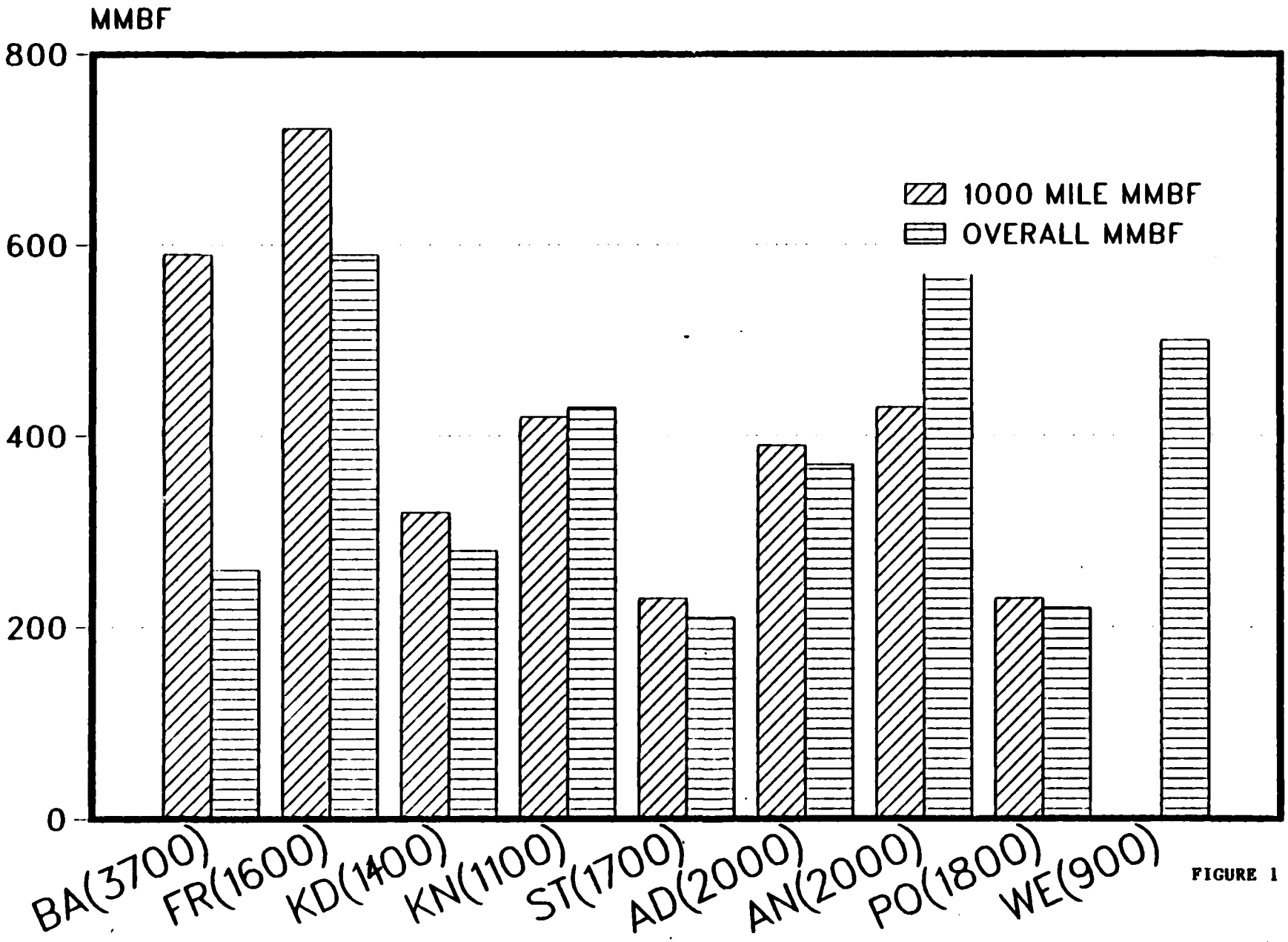


FIGURE 1

SYSTEM CRITERIA MMBF

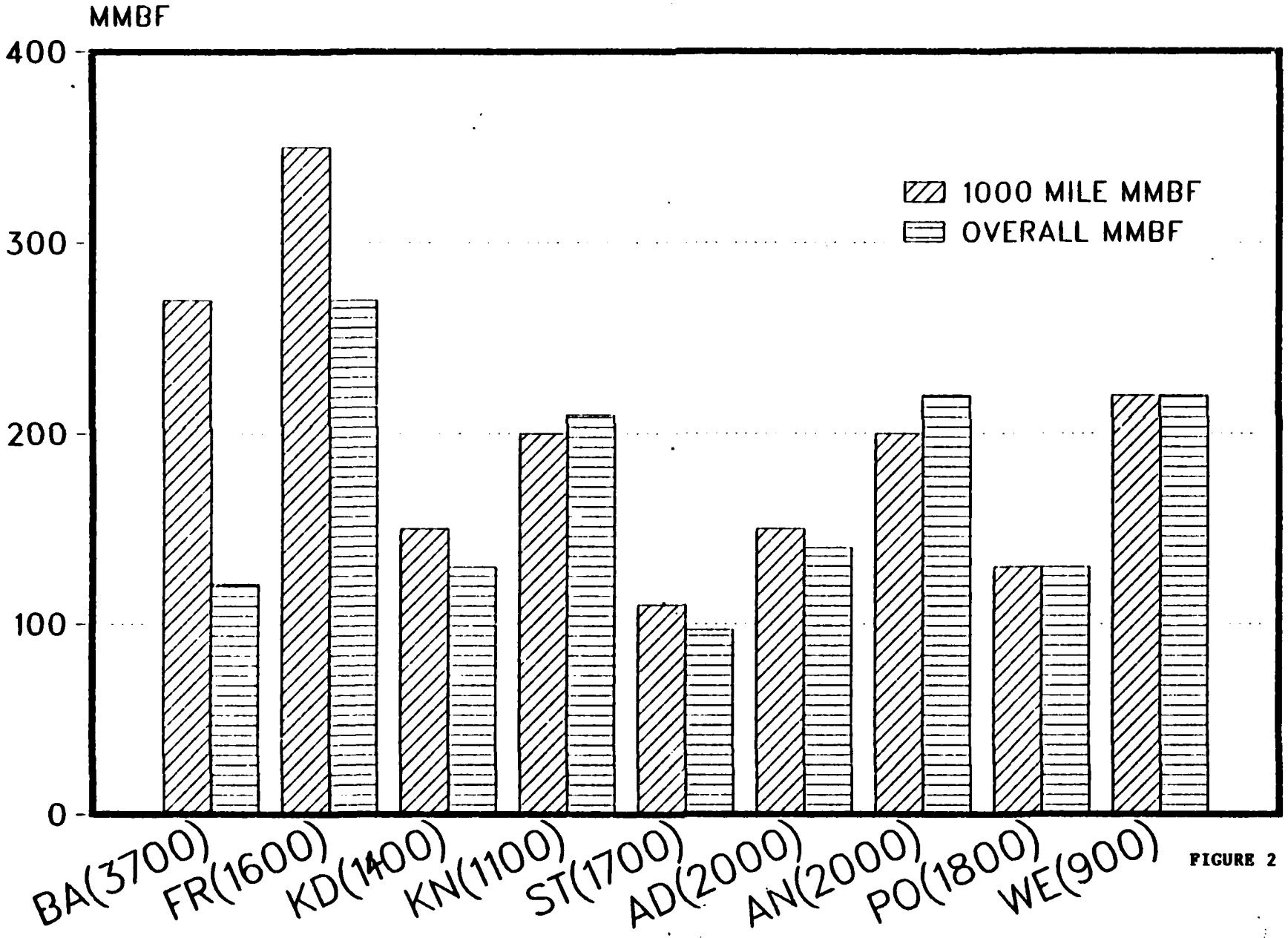


FIGURE 2

FIG 2

HULL – SYSTEM CRITERIA MMBF

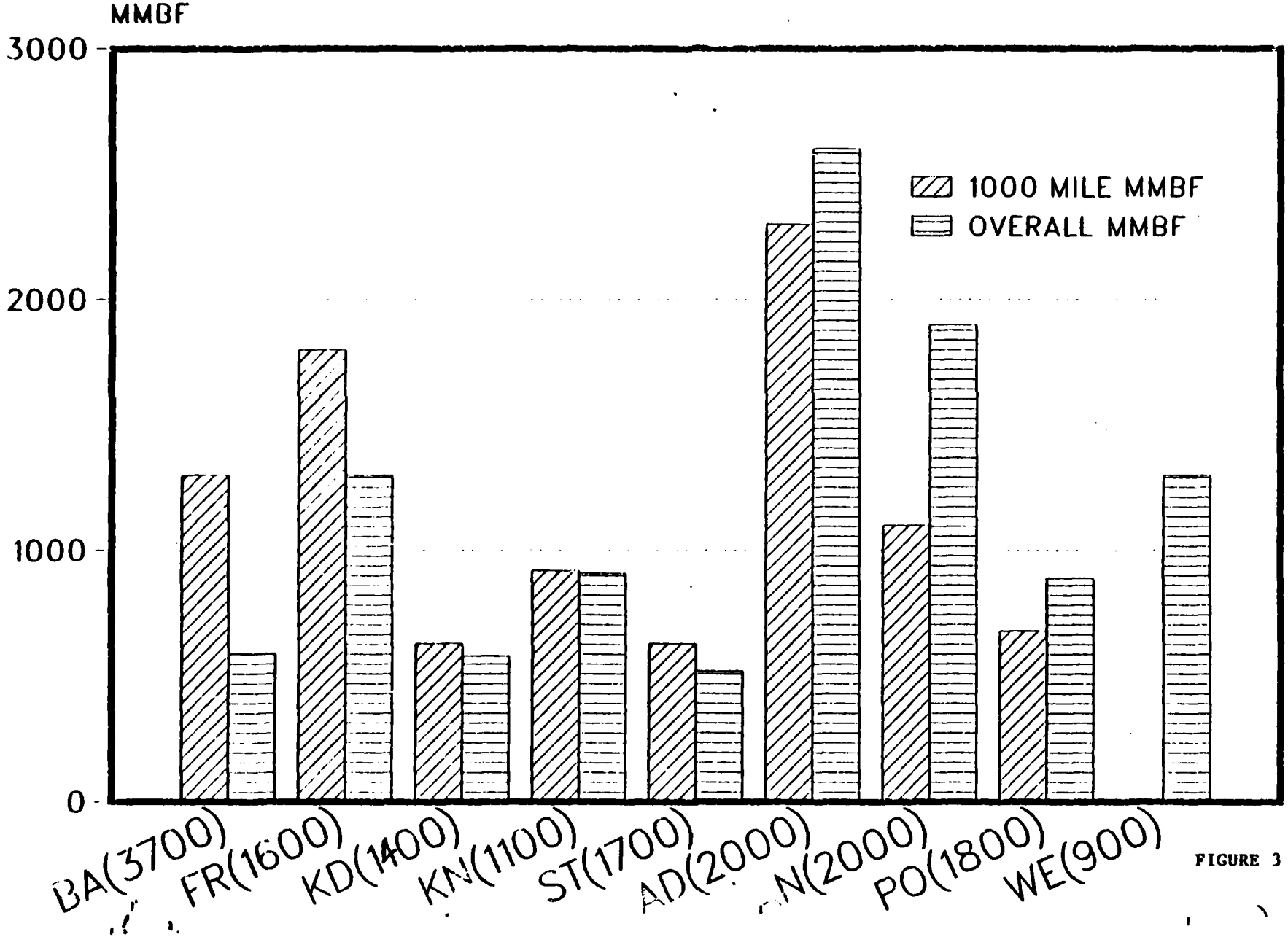


FIGURE 3

PROPULSION – SYSTEM CRITERIA MMBF

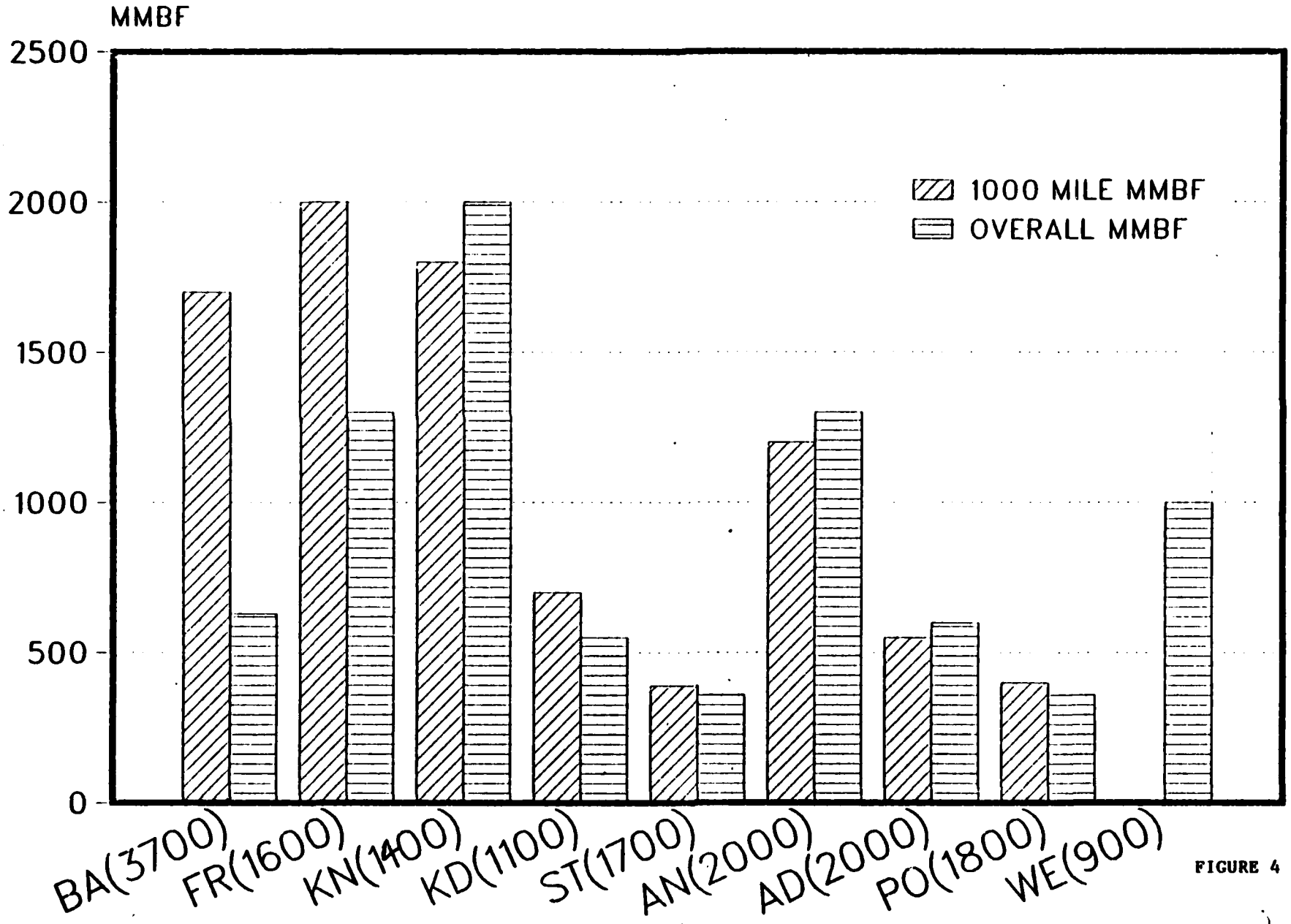


FIGURE 4

FIRE CONTROL – SYSTEM CRITERIA MMBF

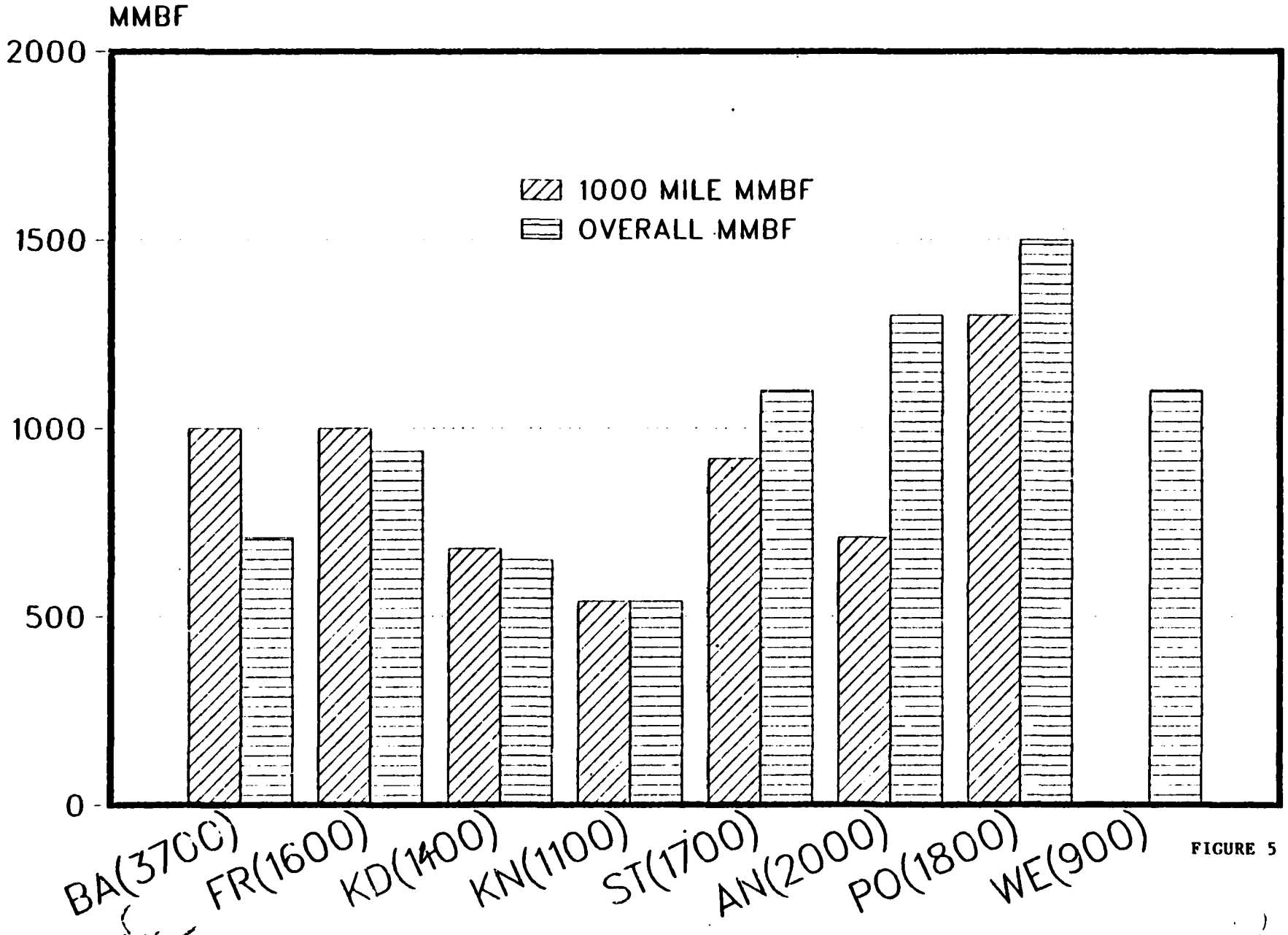


FIGURE 5

SUSPENSION & TRACK – SYSTEM CRITERIA MMBF

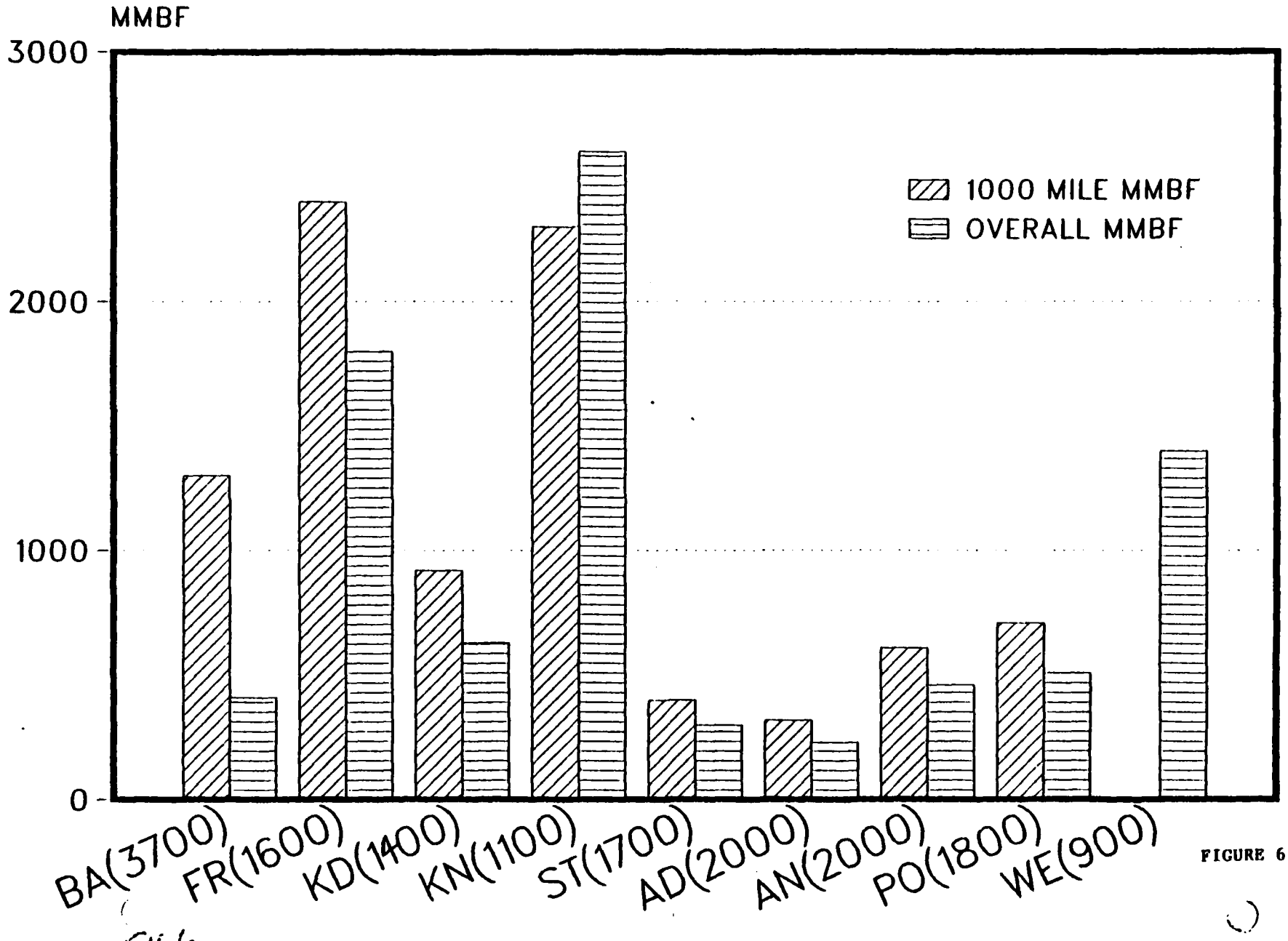


FIGURE 6

FIG 6

Even with an additional 12 to 18 months of SDC data it is likely that due to the low incidents of failure in the turret control, armament and firepower, communications, survival, protection and ancillary subsystems it will not be possible to detect any significant differences. It should also be mentioned that the fire control systems were not identical at all sites adding a further source of bias to that system.

The following tables show the MMBF calculated from the scored failures per vehicle per hundred miles data. It should be pointed out that vehicles with higher test miles will have a greater weight in this MMBF than in one calculated in a more normal fashion. This is due to the MMBF being calculated from the normalized failures per vehicle per hundred miles data. Thus a point at 3000 miles represents fewer vehicles than one at 2000 miles (some of them haven't gone that far yet) but is weighted the same.

MMBF Tables

Total MMBF System Criteria

Location	Bamberg	Freiberg	Kirchgoens	Kirchgoens	Weisbaden	Ft. Stewart	APG	APG	Ft. Polk
Status	New	New	Depot	New	New	Depot	Depot	New	Depot
Miles	3700	1600	1400	1100	900	1700	2000	2000	1800
Subsystem									
Propulsion	630	1300	550	2000	1000	360	600	1300	360
S&T	410	1800	630	2600	1400	300	230	460	510
Hull	590	1300	580	910	1300	520	2600	1900	840
A&F	5000+	5000+	5000+	5000+	5000+	5000+	5000+	5000+	5000+
Gun Cntrl	2000	4300	2000	2000	2800	1600	1900	5000+	1800
Fire Cntrl	710	940	650	540	1100	1100	5000+	1300	1500
Tur Cntrl	3200	5000	3100	2500	4300	2400	5000+	5000+	2900
Misc.	5000+	3300	5000+	5000+	2900	5000+	5000+	5000+	3000
Overall	121	270	130	210	220	97	140	220	130

Total MMBF Mission Criteria

Location	Bamberg	Freiberg	Kirchgoens	Kirchgoens	Weisbaden	Ft. Stewart	APG	APG	Ft. Polk
Status	New	New	Depot	New	New	Depot	Depot	New	Depot
Miles	3700	1600	1400	1100	900	1700	2000	2000	1800
Subsystem									
Propulsion	1300	2900	840	3300	2300	570	830	2200	470
S&T	1700	4200	4000	5000+	5000+	1700	1000	1800	2400
Hull	900	2600	960	1500	1900	830	4500	3300	1100
A&F	5000+	5000+	5000+	5000+	5000+	5000+	5000+	5000+	5000+
Gun Cntrl	5000+	5000+	3700	4800	5000+	2600	5000+	5000+	2600
Fire Cntrl	1500	2300	1900	1100	2300	2900	2000	2700	3300
Tur Cntrl	5000+	5000+	5000+	4500	5000+	5000	5000+	5000+	5000
Misc.	5000+	5000+	5000+	5000+	5000+	3300	5000+	5000+	4800
Overall	260	590	280	430	500	210	370	580	220

First 1000 Mile MMBF System Criteria

Location	Bamberg	Freiberg	Kirchgoens	Kirchgoens	Weisbaden	St. Stewart	APG	APG	Ft. Polk
Status	New	New	Depot	New	New	Depot	Depot	New	Depot
Subsystem									
Propulsion	1700	2000	700	1800	1000	390	550	1200	400
S&T	1300	2400	920	2300	1400	400	320	610	710
Hull	1300	1800	630	920	1300	630	2300	1100	680
A&F	5000+	5000+	5000+	5000+	5000+	4700	5000+	5000+	5000+
Gun Cntrl	5000+	5000+	1700	1800	2800	1700	1200	5000+	1700
Fire Cntrl	1000	1000	680	540	1100	920	5000+	710	1300
Tur Cntrl	5000+	5000+	2500	2200	4300	2400	3900	5000+	2900
Misc.	5000+	5000+	5000+	5000+	2900	4000	5000+	5000+	2200
Overall	270	350	150	200	220	110	150	200	130

First 1000 Mile MMBF Mission Criteria

Location	Bamberg	Freiberg	Kirchgoens	Kirchgoens	Weisbaden	Ft. Stewart	APG	APG	Ft. Polk
Status	New	New	Depot	New	New	Depot	Depot	New	Depot
Subsystem									
Propulsion	4200	3600	1100	3000	2300	600	730	2000	620
S&T	5000+	5000+	4100	5000+	5000+	1900	1500	1800	3300
Hull	2100	3200	1000	1500	1900	1000	5000+	1800	900
A&F	5000+	5000+	5000+	5000+	5000+	5000+	5000+	5000+	5000+
Gun Cntrl	5000+	5000+	3500	4400	5000+	2800	4000	5000+	2400
Fire Cntrl	2000	2600	1800	1100	2300	2700	5000+	1500	3000
Tur Cntrl	5000+	5000+	5000+	4100	5000+	5000+	5000+	5000+	5000
Misc.	5000+	5000+	5000+	5000+	5000+	5000+	5000+	5000+	3600
Overall	590	722	320	420	500	230	390	430	230

S&T - Suspension and Track
A&F - Armament and Firepower
Gun Cntrl - Gun Control
Fire Cntrl - Fire Control
Tur Cntrl - Turret Control
Misc - Communications, Survival, Protection, and Ancillary Subsystems
5000+ - MMBF is greater than 5000 miles

On the 1000 mile charts the failure rate for Weisbaden is the same as the overall failure rate since Weisbaden was only analyzed for 900 miles.

While the data will not currently support conclusions on the overall reliabillity of new vs depot M60's, some statements can be made. The data does indicate that:

1. The vehicles at Bamberg and the new vehicles at APG have lower failure rates than the vehicles at Ft. Stewart, Ft. Polk, and depot vehicles at Kirchgoens.

2. The vehicles at Freiberg have lower failure rates than the vehicles at Ft. Stewart.

3. In general, the vehicles in Germany, with some exceptions, tend to be more reliable than the vehicles in the US, particularly in the less reliable subsystems.

Looking at the system failure data for the first 1000 miles and comparing new vs depot, the following statements can be made:

1. Nothing meaningful can be said about the following subsystems: armament and firepower, fire control, turret control, communications, survival, protection and ancillary subsystems.

2. For the propulsion and gun control subsystems, and for the overall vehicle, the new vehicles all have higher MMBF's than all of the depot vehicles. The propulsion subsystem (depot vehicles) reliability may be explained for the most part by the problem studied in Reference 1. For the gun control subsystem, it should be pointed out that the MMBF is over 2500 miles for all locations which means that while the subsystem is very reliable, conclusions based on this data may not be drawn due to the very limited number of failures.

3. For the suspension and track subsystems, with the exception of the new vehicles at APG, all of the new vehicles have a higher MMBF than any of the depot vehicles.

4. For hull systems both the new and depot vehicles from APG are anomalous with respect to the rest of the data which again shows a higher MMBF for the new vehicles.

It should be pointed out that while the above statements compare new to depot vehicles the differences are not necessarily a consequence of depot treatment. Also, this is data from the first 1000 miles only and the above conclusions may not be supported from the total MMBF data.

Mileage Dependency Tables

In these tables, a "+" indicates that a failure rate is increasing with vehicle miles. A "-" indicates a failure rate that is decreasing with test miles. A "0" indicates no statistically significant relationship between failures and vehicle miles. The relationship was judged significant if the following two criteria were met: 1. The 95% confidence limits on the slope did not include 0 slope. 2. The correlation coefficient indicated that there is a relationship that exists at a confidence level of 95% or more. The systems are as follows: 1 = Propulsion; 2 = Suspension and Track; 3 = Hull; 4 = Armament and Firepower; 5 = Gun Control; 6 = Fire Control; 7 = Turret Control; 8 = Communications, Survival, Protection, and Ancillary Subsystems; all = the total vehicle.

Mileage Dependency
System Failures
System

Location	1	2	3	4	5	6	7	8	all
Bamberg	+	+	+	0	+	+	+	+	+
Freiberg	+	+	+	0	+	0	0	0	+
Weisbaden	0	+	0	0	0	-	0	0	0
Kirchgoens New	0	0	0	0	0	0	0	0	0
Kirchgoens Depot	+	+	0	+	0	0	0	0	+
Ft. Stewart	0	+	+	0	0	0	0	0	0
Aberdeen New	0	+	-	0	0	-	0	0	0
Aberdeen Depot	0	+	0	0	0	0	0	0	0
Ft. Polk	+	+	0	0	0	0	0	-	0

Mission Failures
System

Location	1	2	3	4	5	6	7	8	all
Bamberg	+	+	+	0	+	+	0	+	+
Freiberg	+	+	0	0	0	0	0	0	+
Weisbaden	0	0	0	0	0	0	0	0	0
Kirchgoens	0	0	0	0	0	0	0	0	0
Kirchgoesn Depot	+	0	0	+	0	0	0	0	+
Ft. Stewart	0	0	+	0	0	0	0	0	+
Aberdeen New	0	0	-	0	0	-	0	0	0
Aberdeen Depot	0	0	0	0	0	0	0	0	0
Ft. Polk	+	0	0	0	0	0	0	0	0

+ Increasing failure rate with test miles
- Decreasing failure rate with test miles
0 No discernable failure rate vs test miles dependency

Conclusions

The data to date shows a significantly lower MMBF in the depot vehicles as opposed to the new vehicles in the first 1000 miles. The data, particularly on the depot vehicles, is insufficient to allow for conclusions beyond 1000 miles. One of the reasons for the inability to extrapolate reasonably from the data is a strong mileage dependence in some of the data that does not seem to be well defined until 2000 or more miles have been accumulated. It is also not clear at this point how much of the differences in MMBF are due to the depot treatment and how much is due to other causes. When the data base has matured further (12 to 18 months more data should be sufficient) these questions may be resolved.

References:

1. AVDS-1790 RAM/Overhaul Study by TACOM AMSTA-QRA (POC Mr. Roland Baars).
2. Failure Criteria M60A1 RISE Tank, February 1976.
3. Functional Failure Criteria for the M60A1-RISE Tank, March 1976.
4. System Failure Criteria M60A3 Tank, August 1979
5. Mission Failure Criteria M60A3 Tank, August 1979.

Appendix I - First Failure Distribution Parameters

The following distribution parameters will be given for each location: 1) Distribution Type, 2) Alpha, 3) Beta, 4) Mean, 5) Upper 90% confidence limit, 6) Lower 90% confidence limit. The systems are as follows: 1= Propulsion; 2 = Suspension and Track; 3 = Hull; 4 = Armament and Firepower; 5 = Gun Control; 6 = Fire Control; 7 = Turret Control; 8 = Communications, Survival, Protection, and Ancillary Subsystems.

Location	System	Type	Alpha	Beta	Mean	Lower	Upper
APG - Depot	All	Insufficient data					
APG - New	1, 4, 5, 7, 8	Insufficient data					
	2	Weibull	1.3679	682.5504	624	376	910
	3	Weibull	.9114	730.7756	764	322	1254
	6	Weibull	.6640	335.4158	448	164	1029
Bamberg	1	Weibull	1.6813	1355.3329	1208	1019	1408
	2	Weibull	1.5416	999.4877	899	743	1063
	3	Weibull	1.4187	1041.5048	947	784	1148
	4	Exponential	1.0	1425.2286	1425	1017	1966
	5, 8	Insufficient data					
	6	Weibull	1.7682	859.7242	755	647	882
	7	Weibull	1.4380	1816.0049	1648	1317	2001
Freiberg	1	Weibull	2.5546	920.4949	803	726	880
	2	Weibull	2.6087	836.3240	727	654	814
	3	Weibull	1.9511	728.0624	643	573	723
	4, 8	Insufficient data					
	5	Weibull	1.9195	887.6513	784	649	930
	6	Weibull	2.1198	634.9997	558	506	626
	7	Weibull	1.9735	751.986	663	545	804
Kirchgoens	1	Weibull	2.8830	713.5717	618	541	687
Depot	2	Weibull	2.1010	730.6421	643	532	741
	3	Weibull	2.5158	648.0821	566	494	642
	4, 8	Insufficient data					
	5	Weibull	2.7611	634.006	551	463	645
	6	Weibull	2.2635	540.5594	474	405	541
	7	Weibull	2.1032	620.2132	546	432	672
Kirchgoens	1, 2, 4, 5, 6, 7, 8	Insufficient data					
New	3	Weibull	2.9949	482.8119			

Ft. Polk	1	Exponential	1.0	360.0227	360	263	485
	2	Weibull	1.5877	632.424	567	456	699
	3	Weibull	.8977	495.5302	522	341	746
	4, 5	Unsufficient data					
	6	Weibull	.6919	388.0342	497	275	849
	7	Weibull	1.2165	692.2156	649	422	940
	8	Weibull	1.0399	458.0028	451	308	639
Ft. Stewart	1	Weibull	.8740	427.0847	457	331	615
	2, 7	Insufficient data					
	3	Exponential	1.0	520.333	520	385	689
	4	Weibull	1.3523	617.0221	565	402	762
	5	Exponential	1.0	625.2439	625	434	851
	6	Exponential	1.0	467.6047	468	341	631
	8	Exponential	1.0	587.1739	587	367	869
Weisbaden	1	Weibull	2.5068	386.1098	337	288	395
	2	Weibull	2.4361	463.8918	406	347	472
	3	Weibull	1.3853	284.9387	260	208	320
	4	Weibull	1.9589	298.3486	368	276	461
	5	Weibull	1.8227	298.3486	264	195	341
	6	Weibull	1.5387	236.4269	212	171	259
	7	Insufficient data					
	8	Weibull	1.4348	446.4792	405	278	562

Appendix II - System Score Scatter Plots

This appendix contains the scatter plots of the systems failure criteria scores for all locations and subsystems for which there was adequate data to make them significant. Also included for comparison purposes are the overall failure scores for the mission failure criteria. In general, the mission criteria tracked the systems criteria but at a lower rate (fewer failures) thus having greater uncertainty and less significance. The data on the armament and firepower; turret control; and communications, survival, protection, and ancillary systems was judged not significant enough to plot.

The following explains the coding of the plot titles.

The first 2 letters indicate location and treatment as follows:

Ba - Bamberg (new vehicles)
Fr - Freiberg (new vehicles)
We - Weisbaden (new vehicles)
KD - Kirchgoen Depot vehicles
KN - Kirchgoen New vehicles
St - Ft. Stewart (depot vehicles)
AD - APG Depot vehicles
AN - APG New vehicles
Po - Ft. Polk (depot M60A1's)

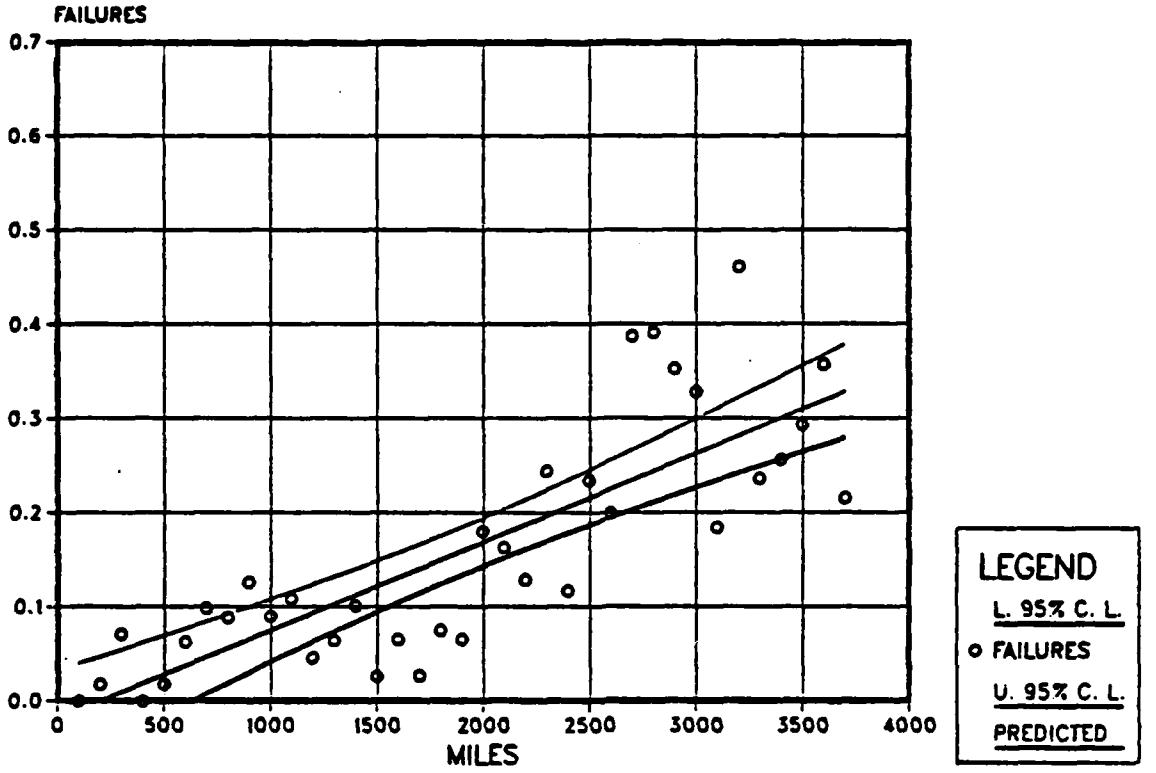
The third letter indicates treatment as follows:

S - System failure criteria score
M - Mission failure criteria score

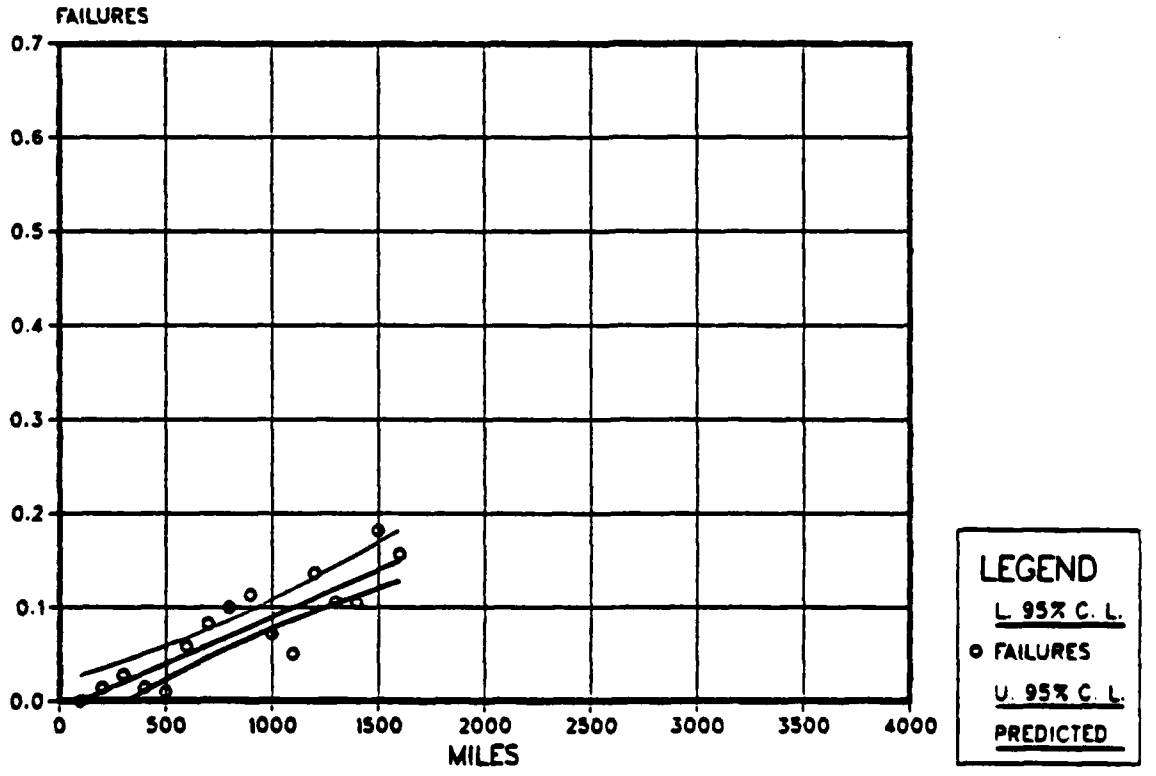
The number indicates system as follows:

1 - Propulsion
2 - Suspension and Track
3 - Hull
5 - Gun Control
6 - Fire Control
9 - Overall

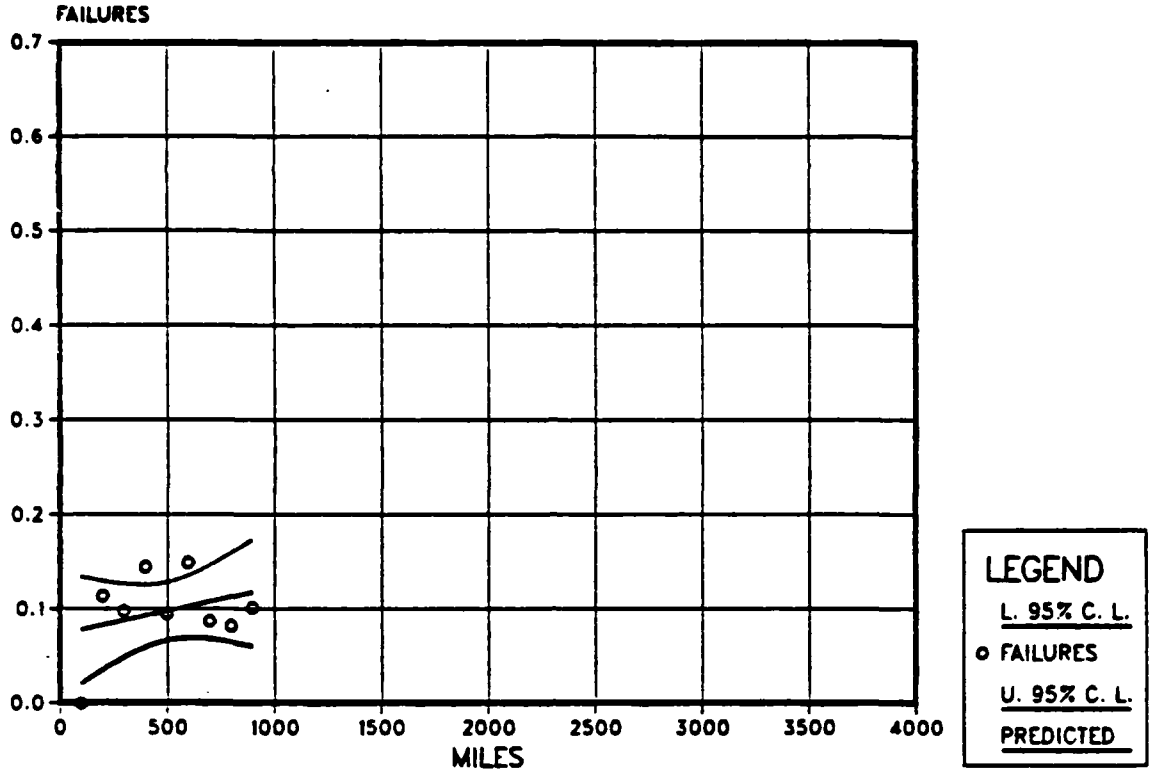
FAILURES PER MILE BA_S.1



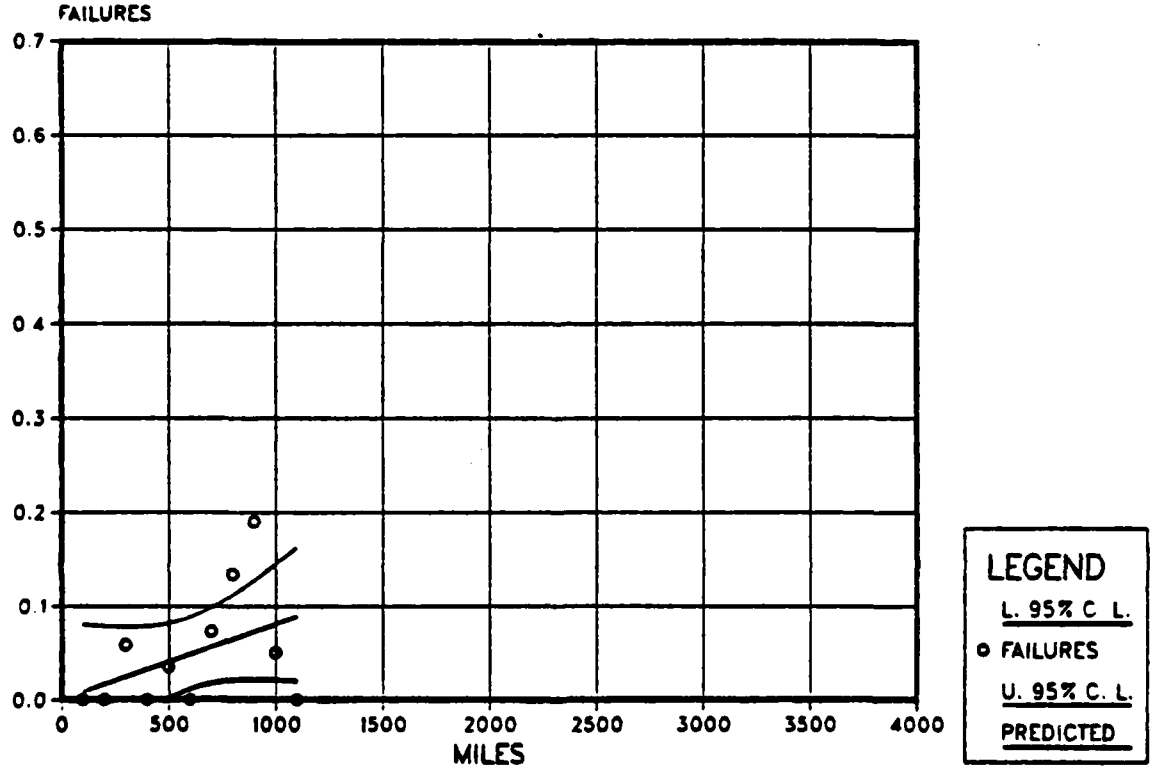
FAILURES PER MILE FR_S.1



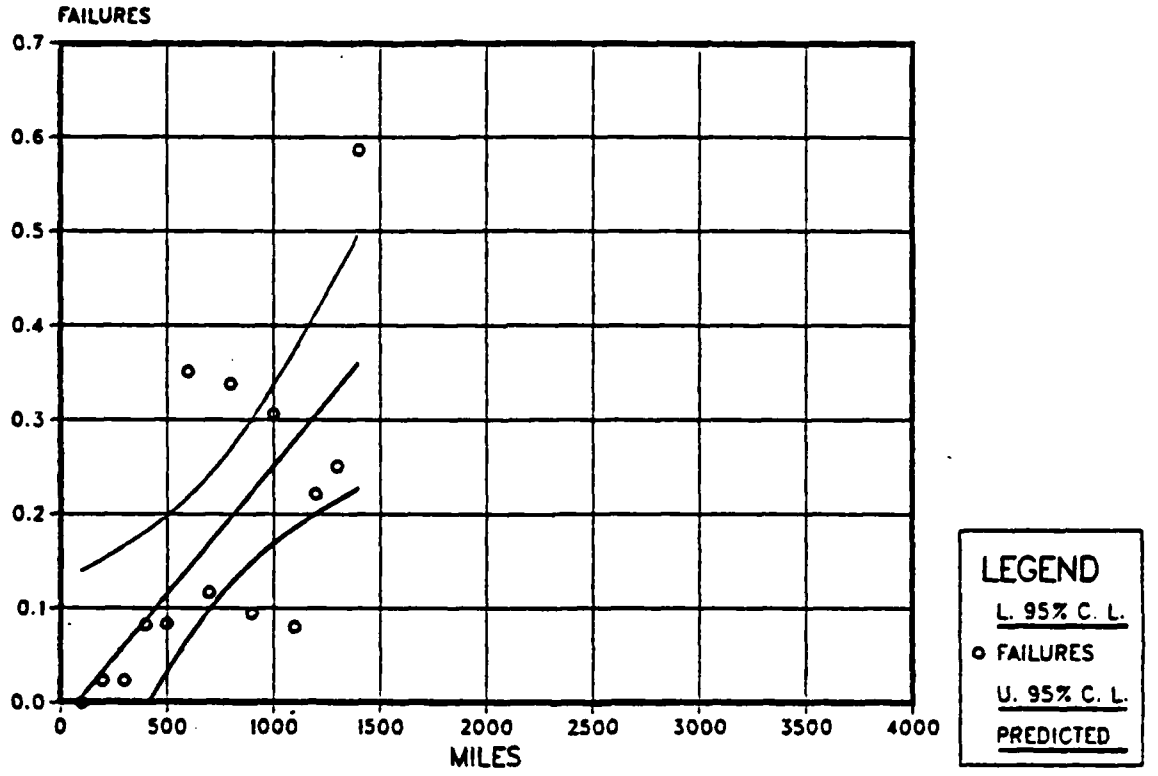
FAILURES PER MILE WE_S.1



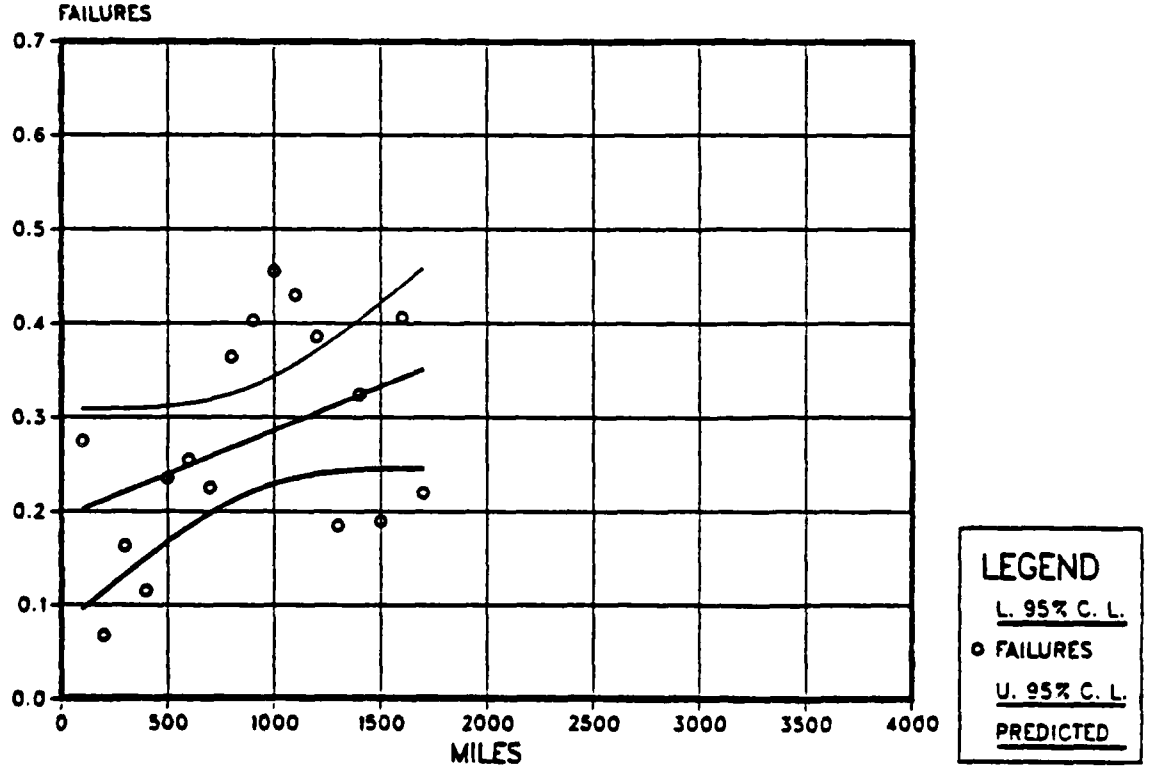
FAILURES PER MILE KN_S.1



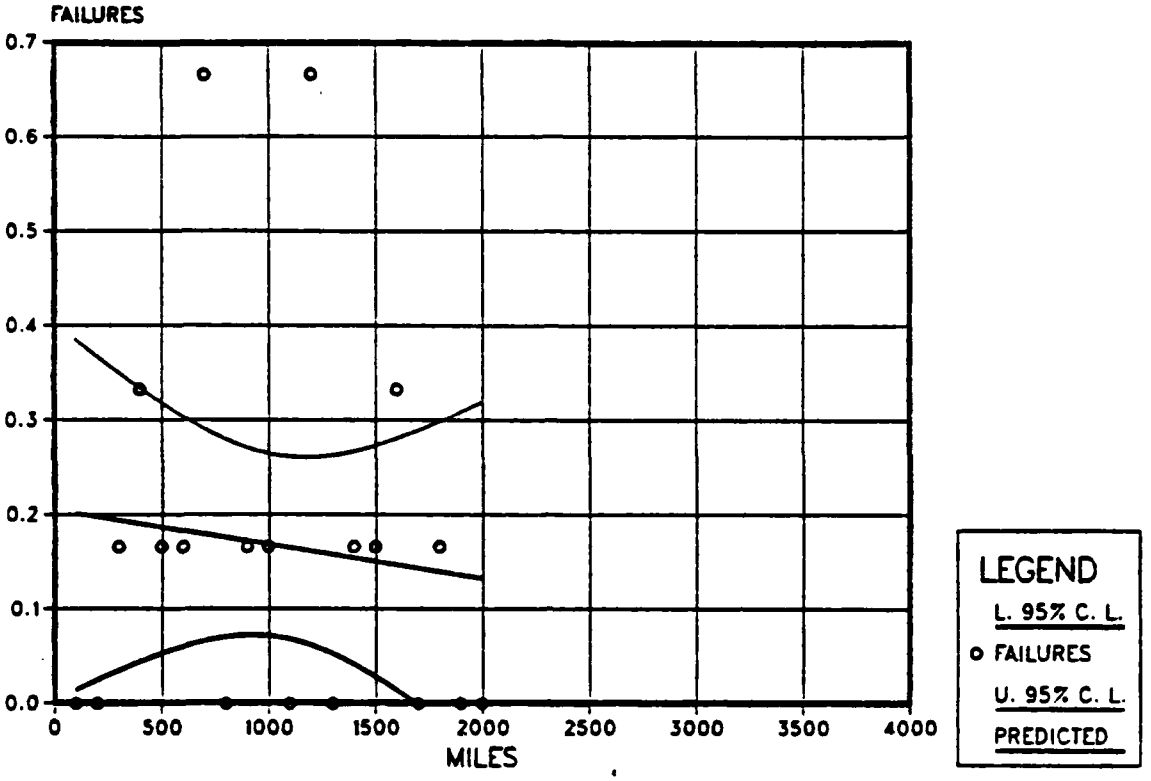
FAILURES PER MILE KD_S.1



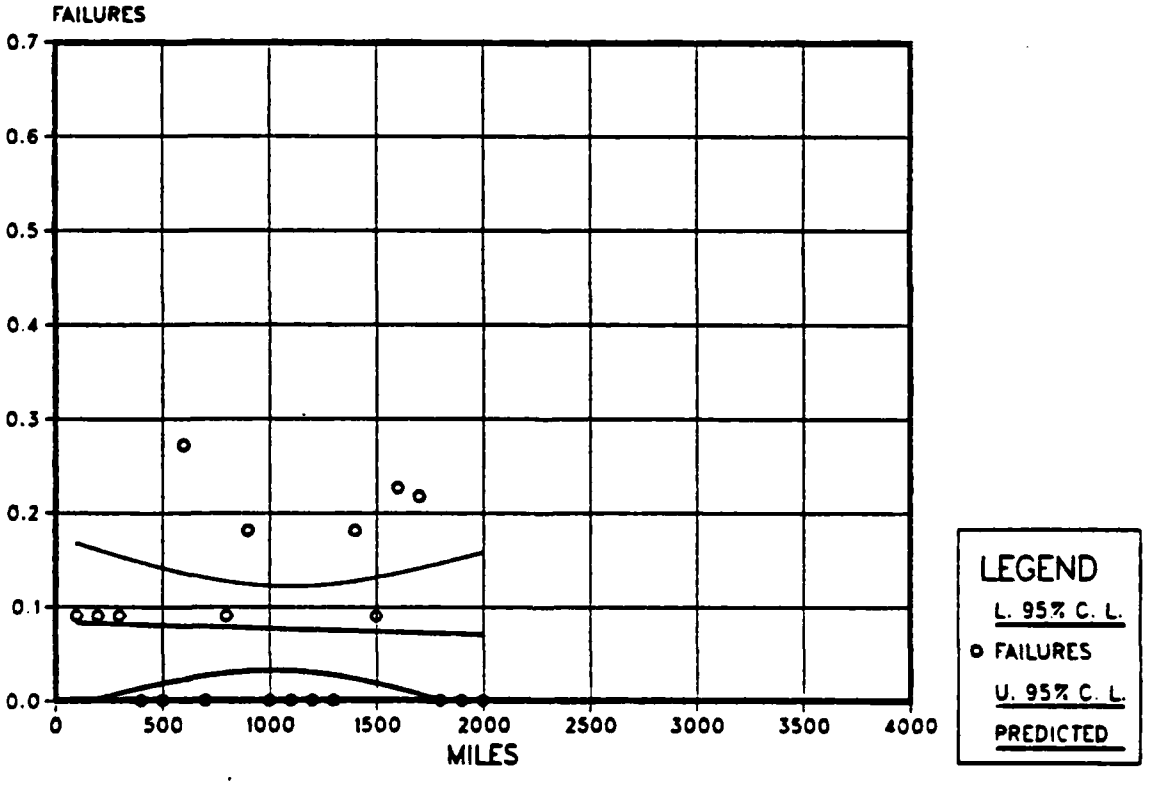
FAILURES PER MILE ST_S.1



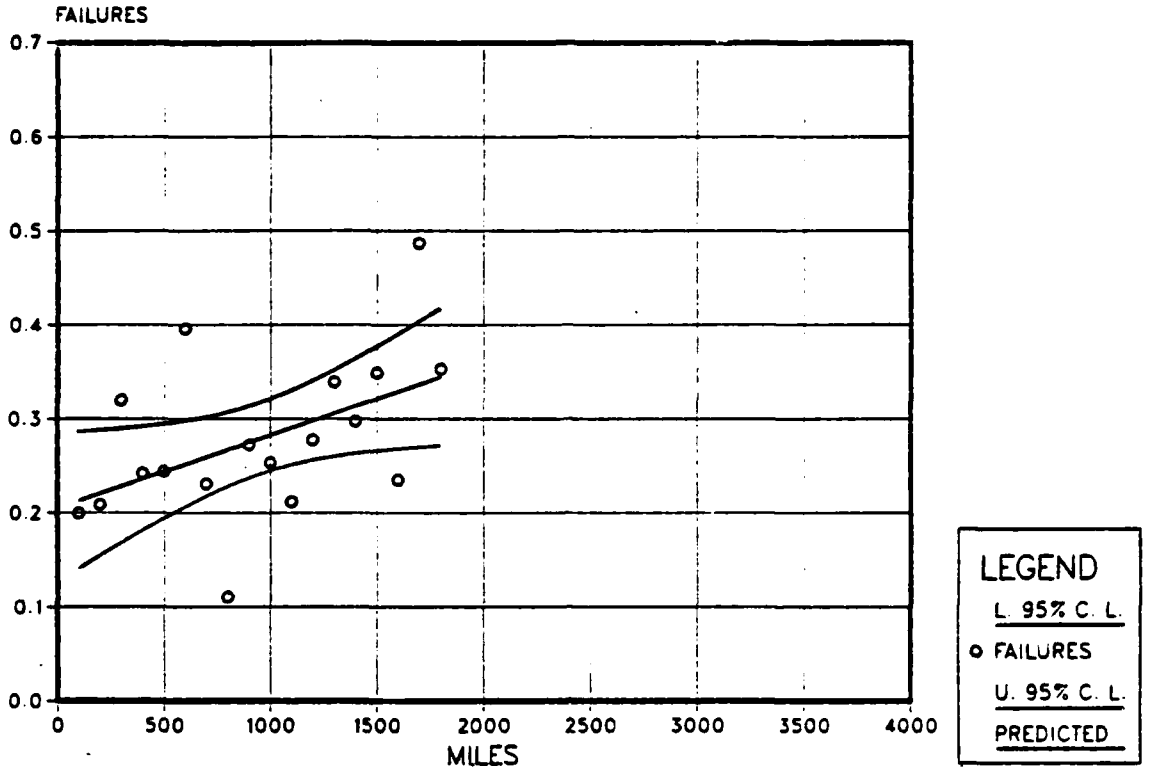
FAILURES PER MILE AD_S.1



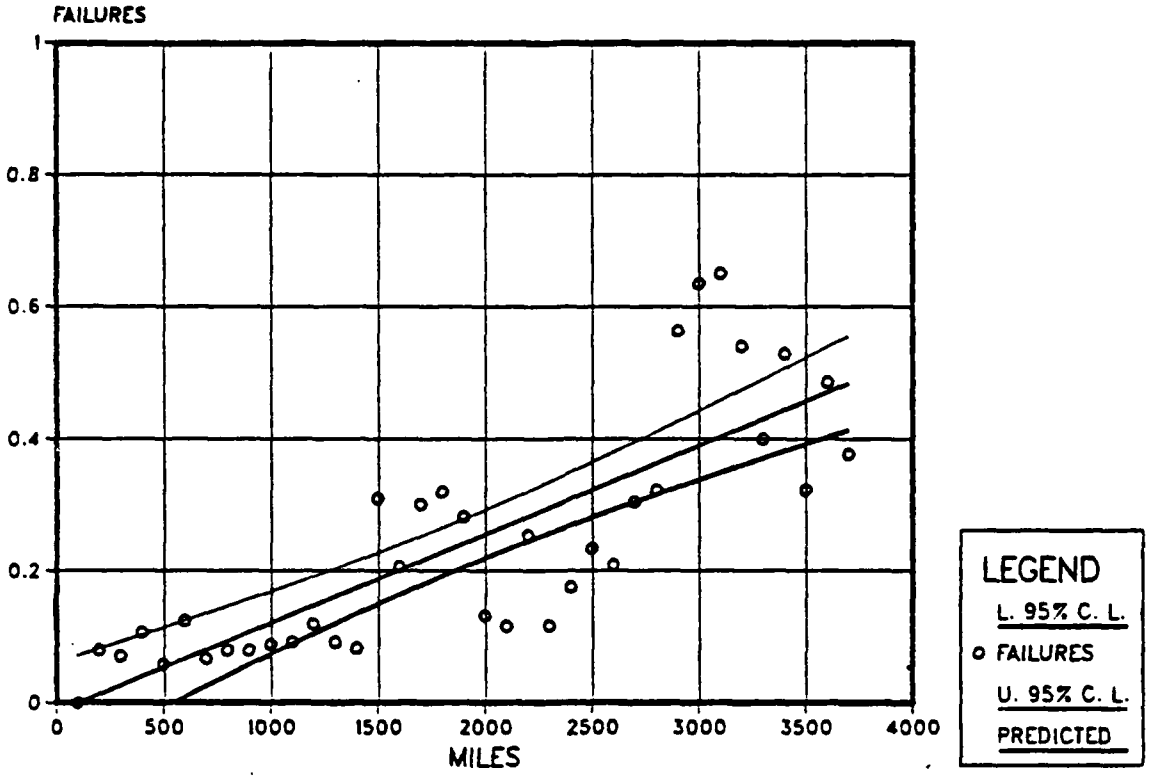
FAILURES PER MILE AN_S.1



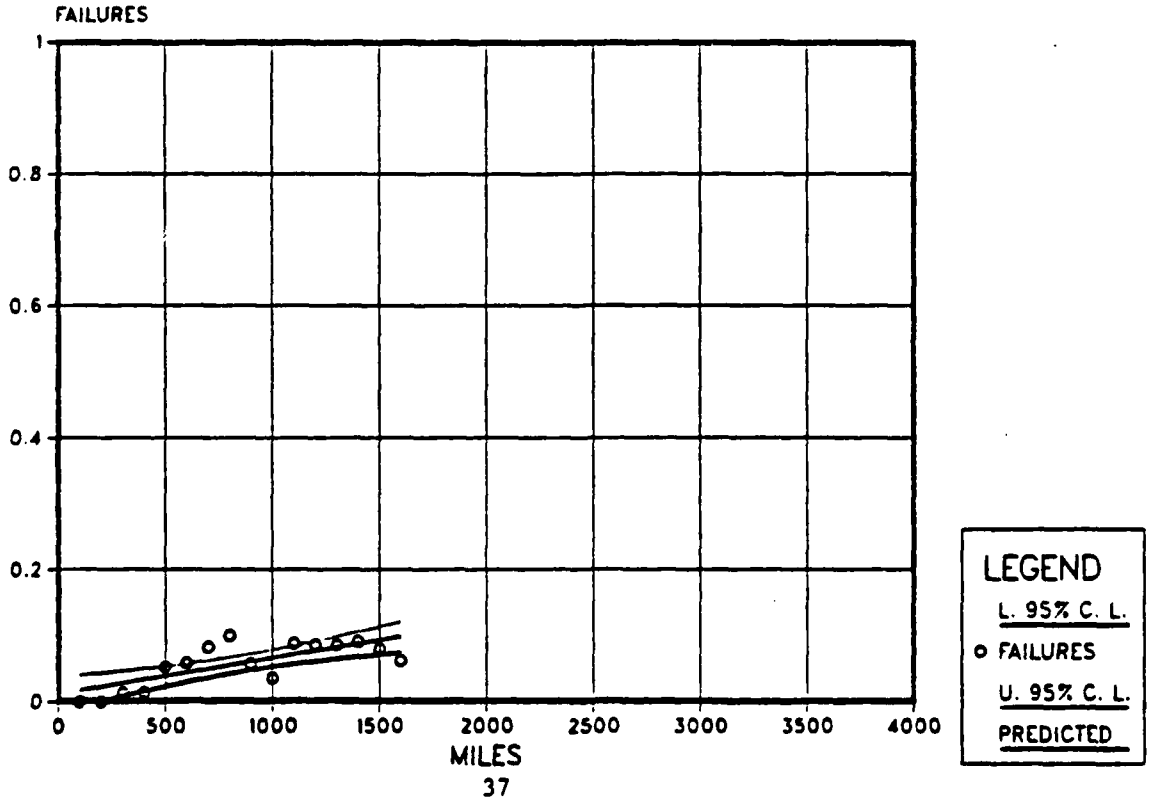
FAILURES PER MILE PO_S.1



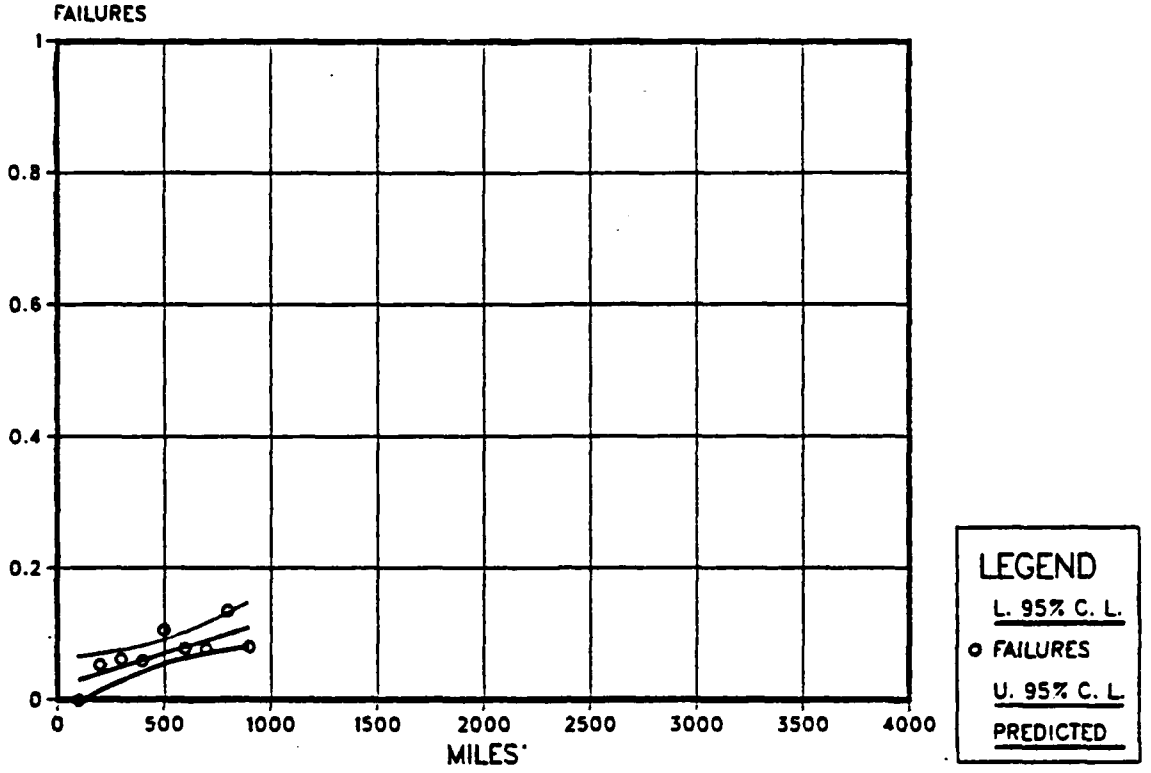
FAILURES PER MILE BA_S.2



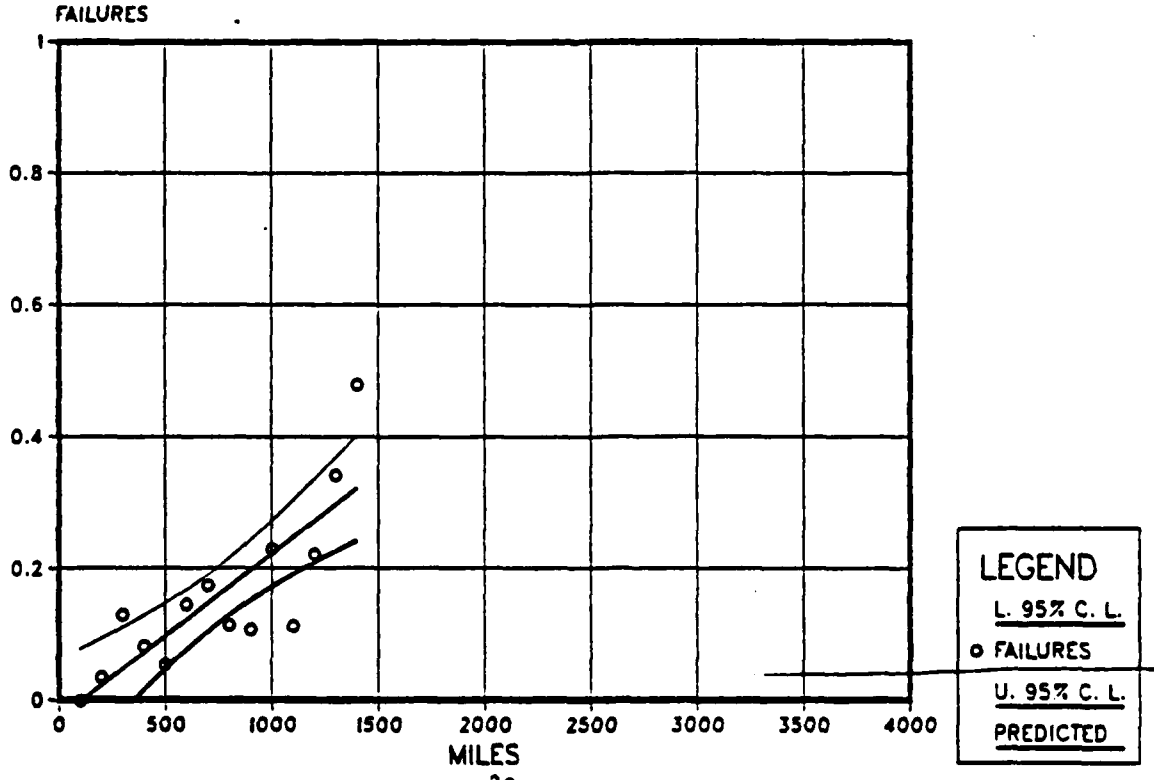
FAILURES PER MILE FR_S.2



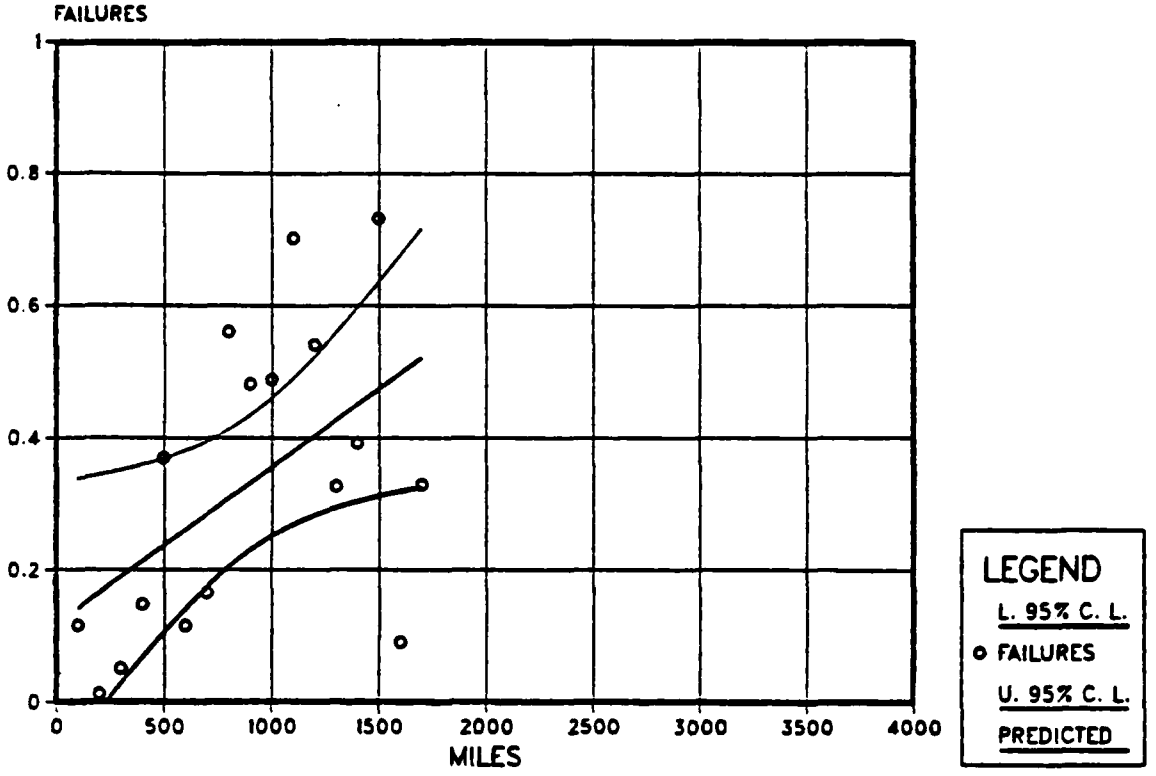
FAILURES PER MILE WE_S.2



FAILURES PER MILE KD_S.2



FAILURES PER MILE ST_S.2



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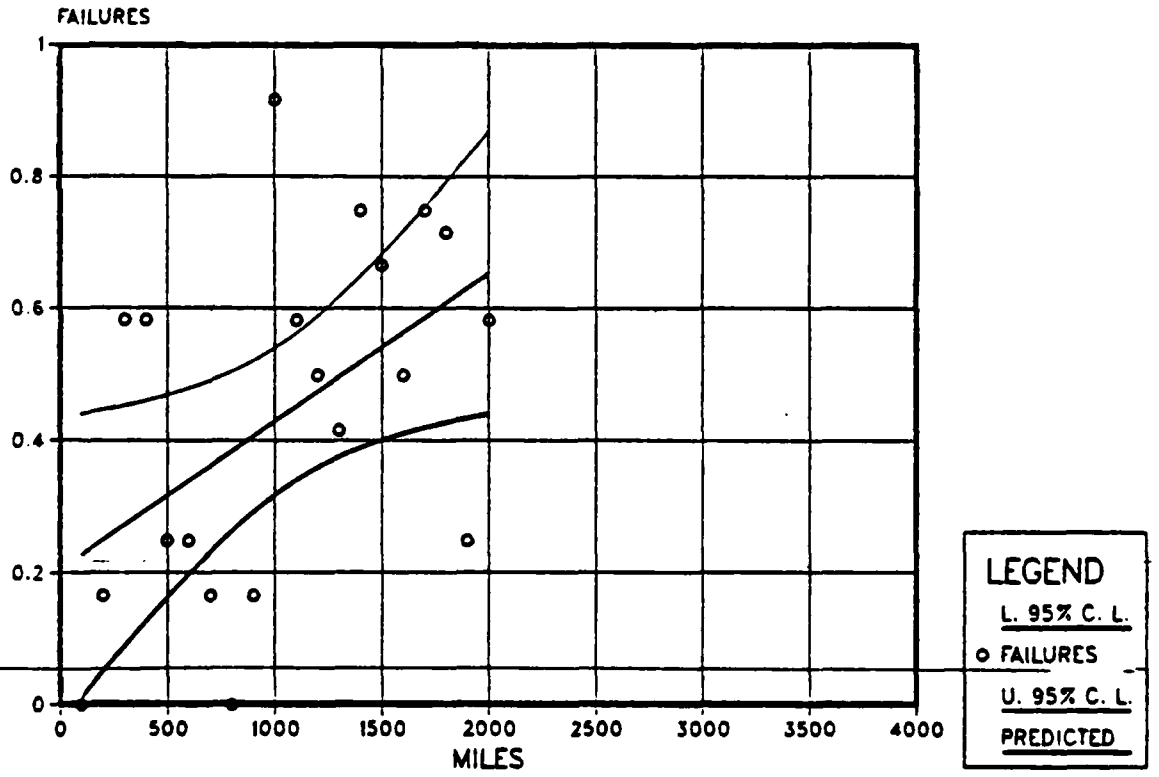

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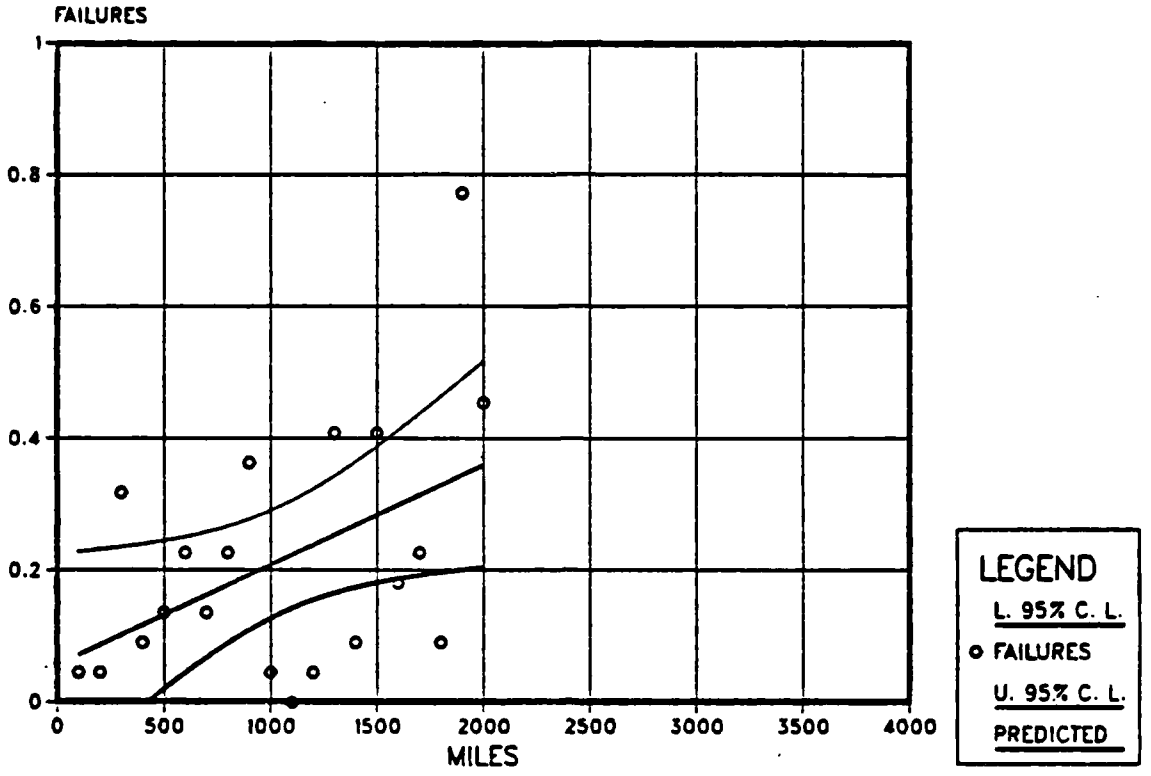

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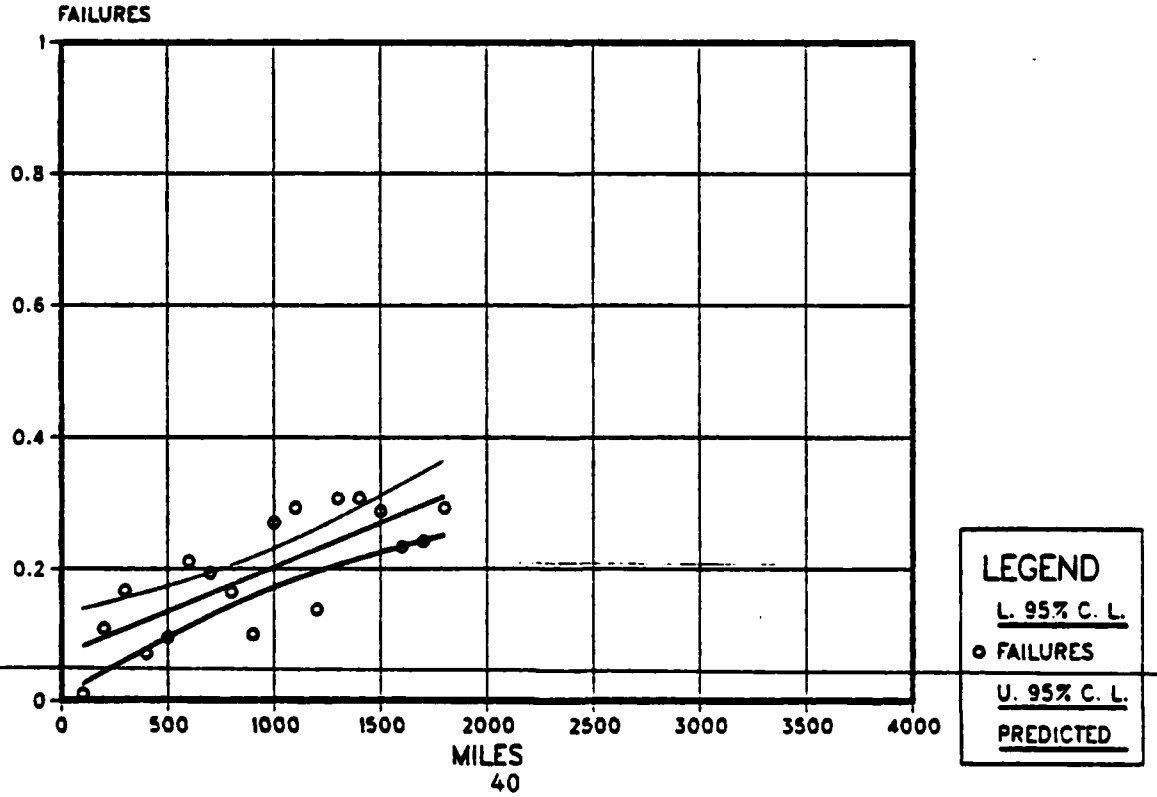

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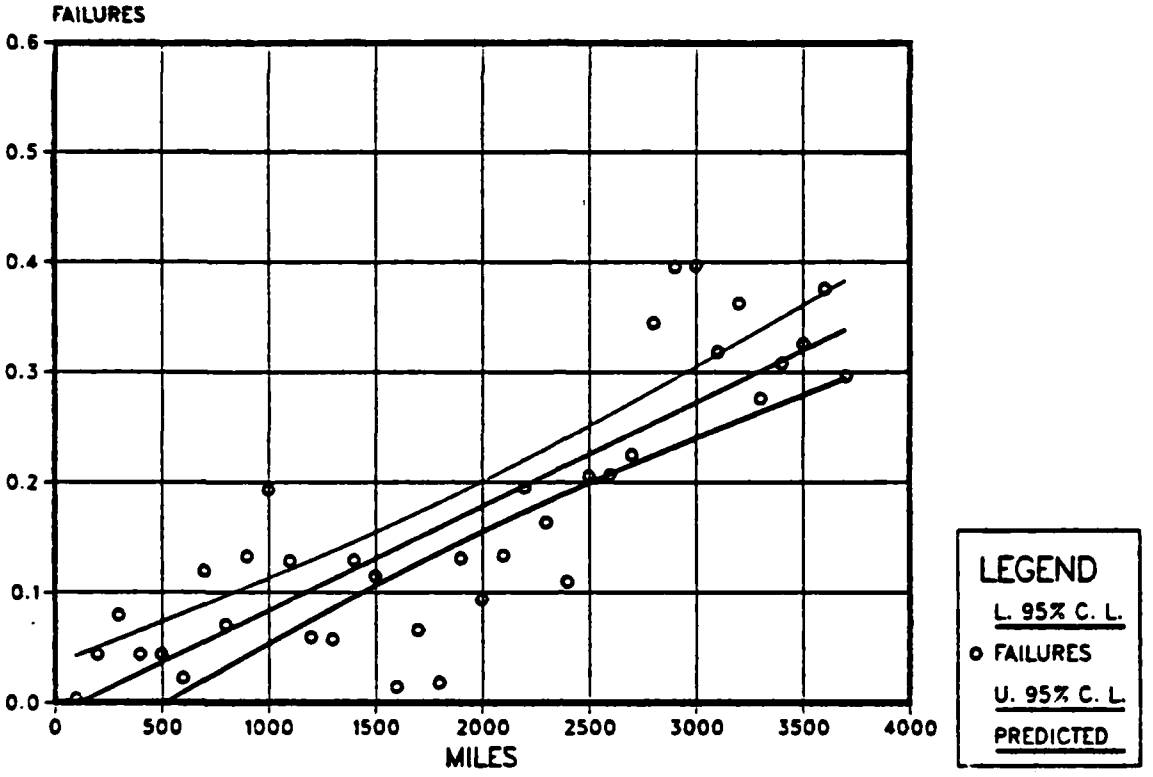

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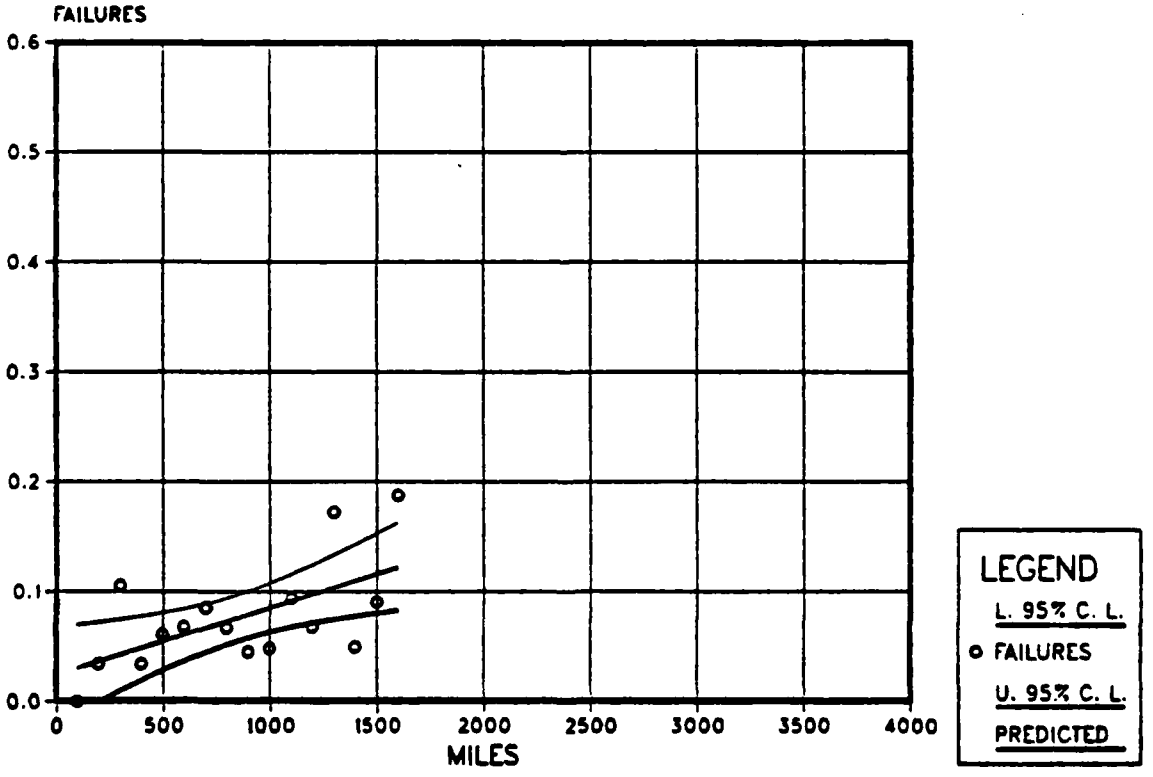

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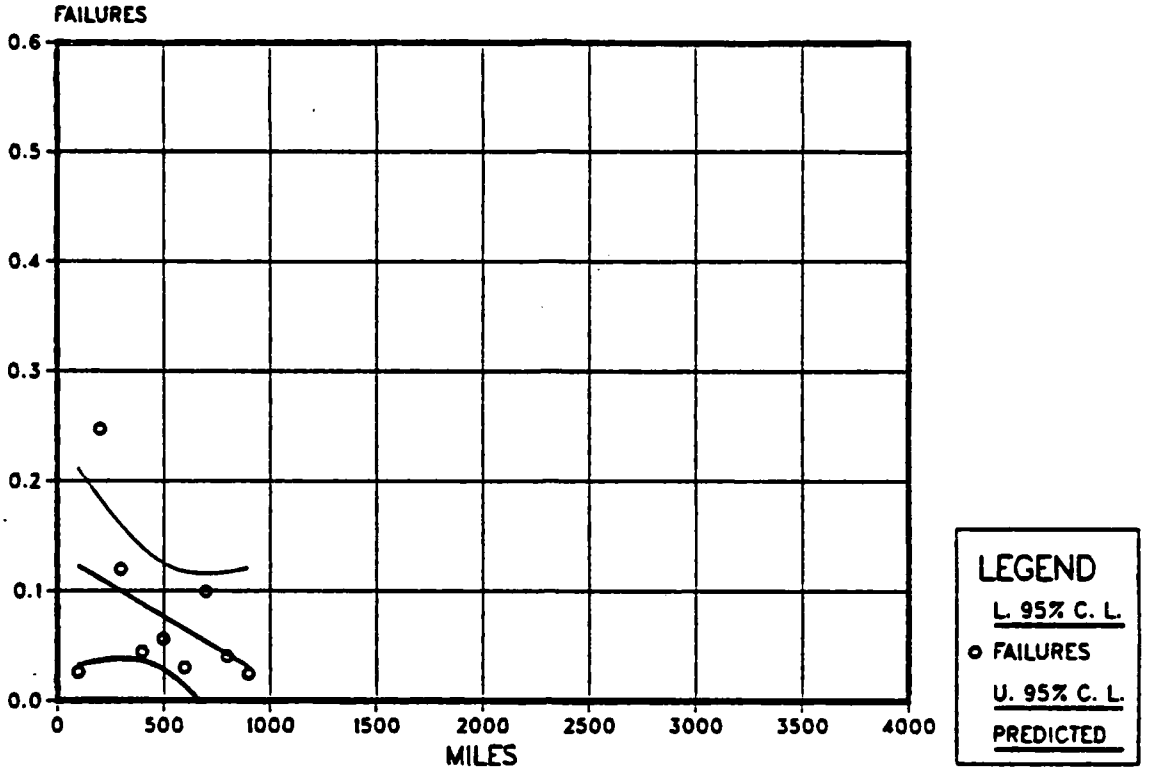

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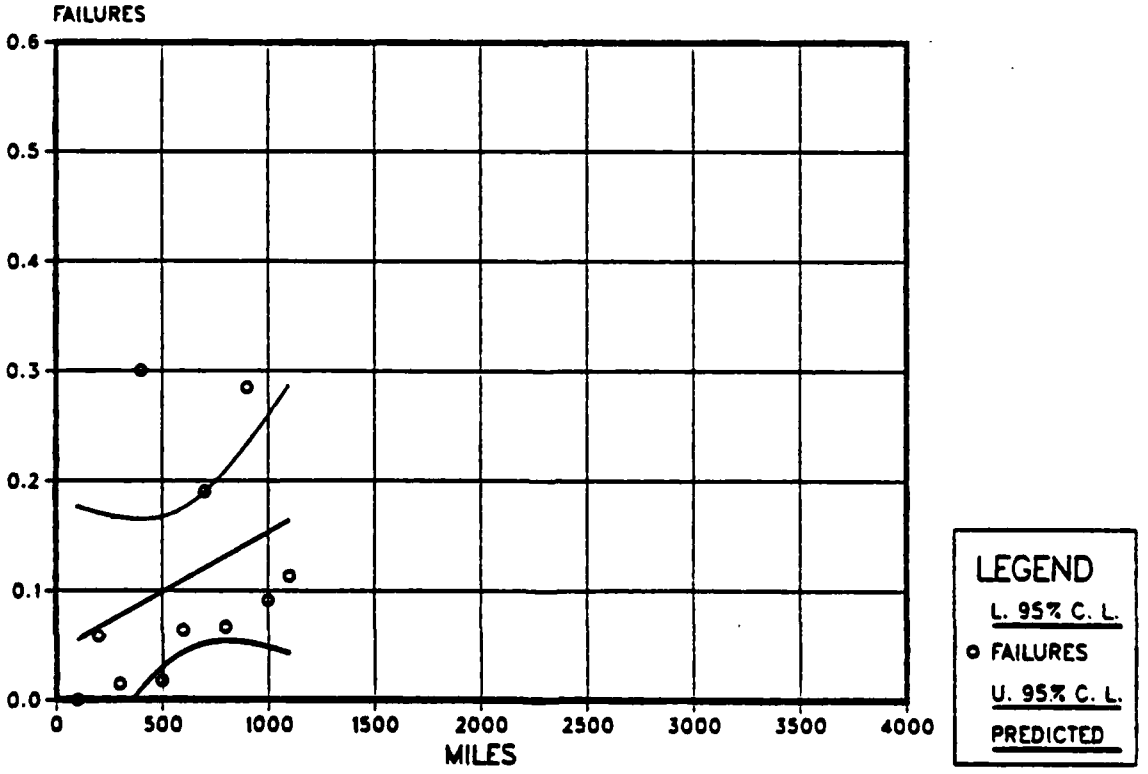

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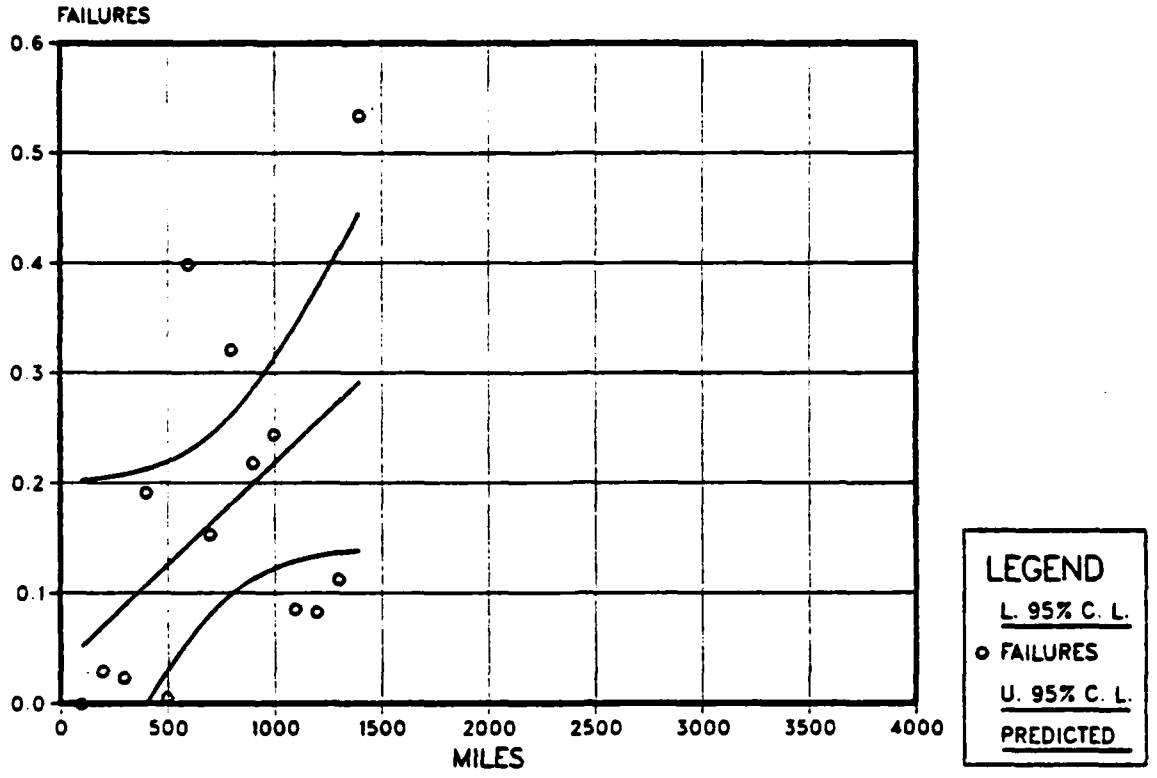

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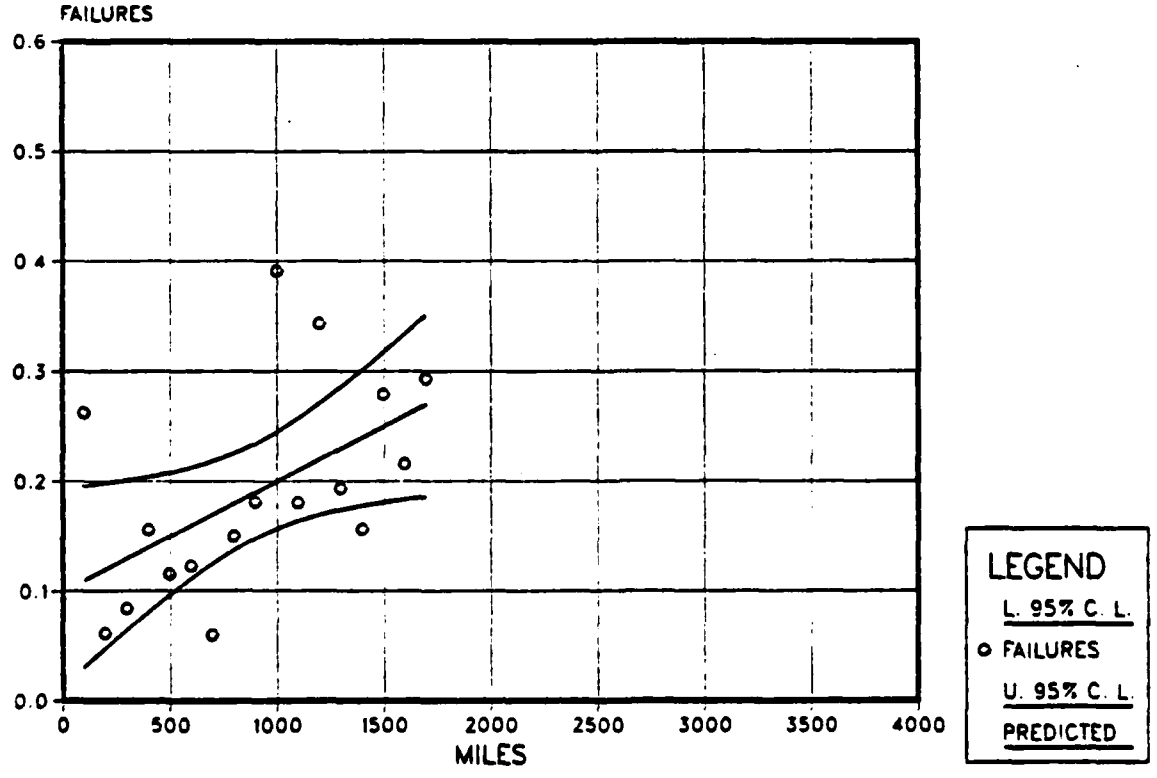

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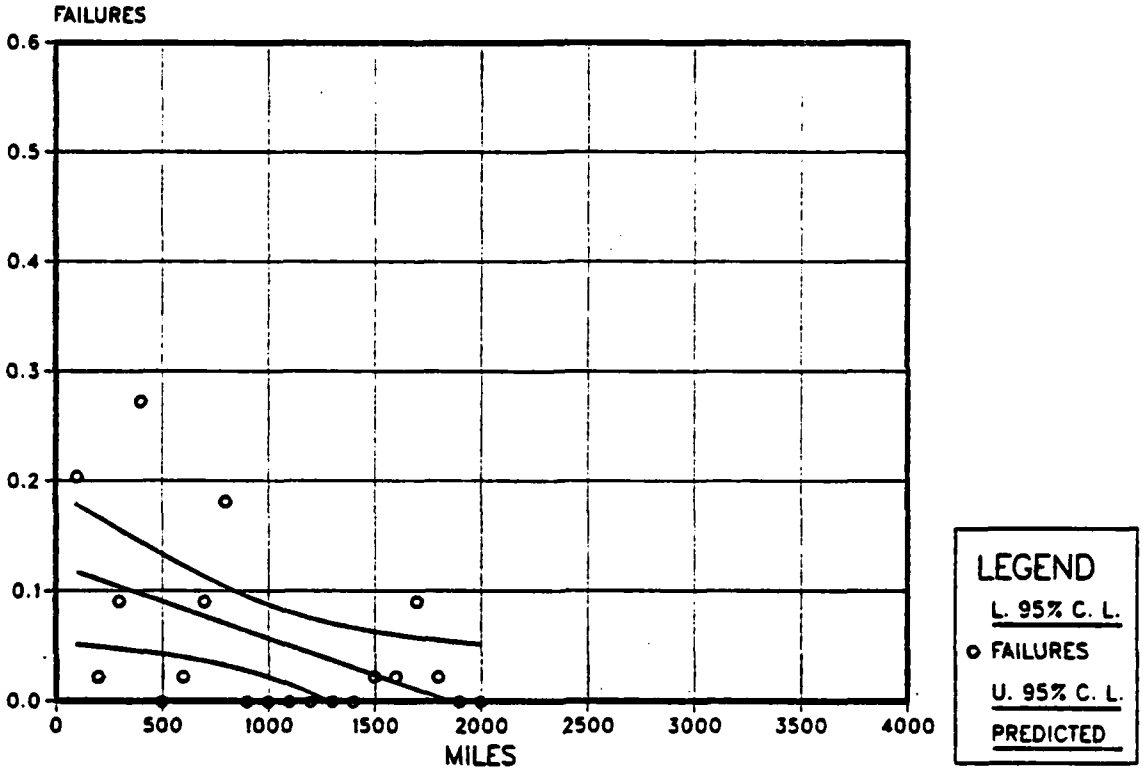

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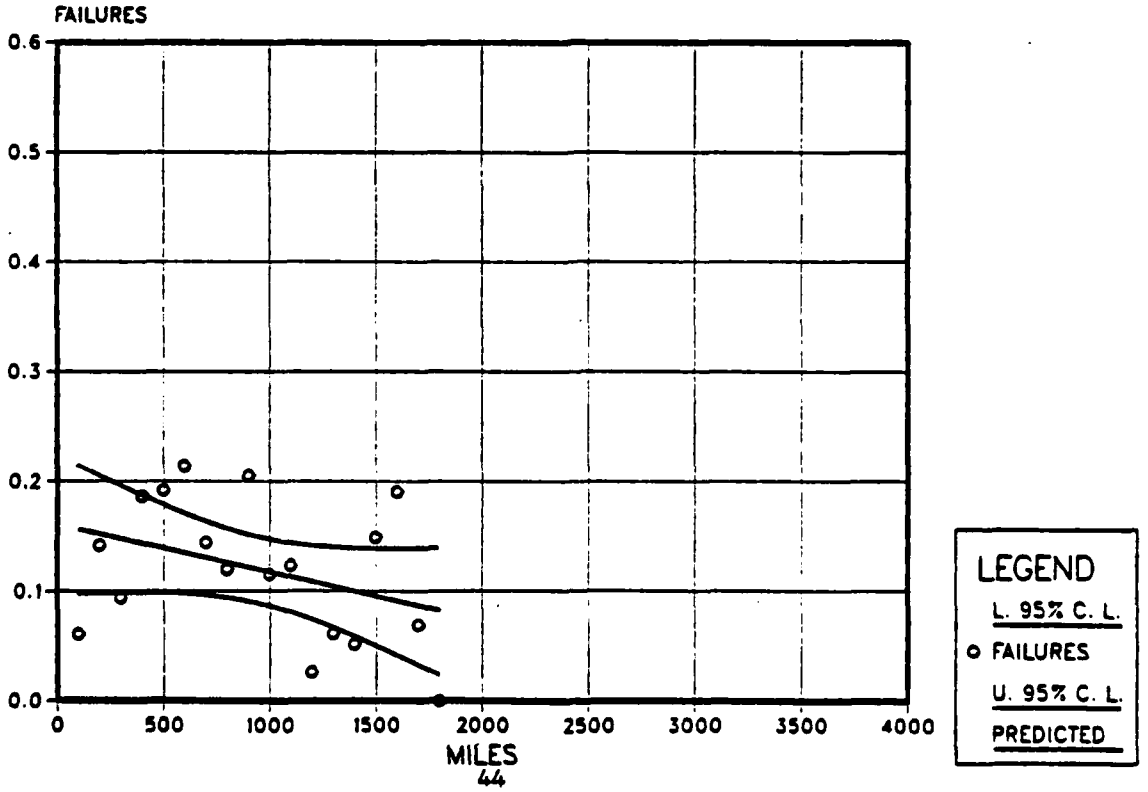

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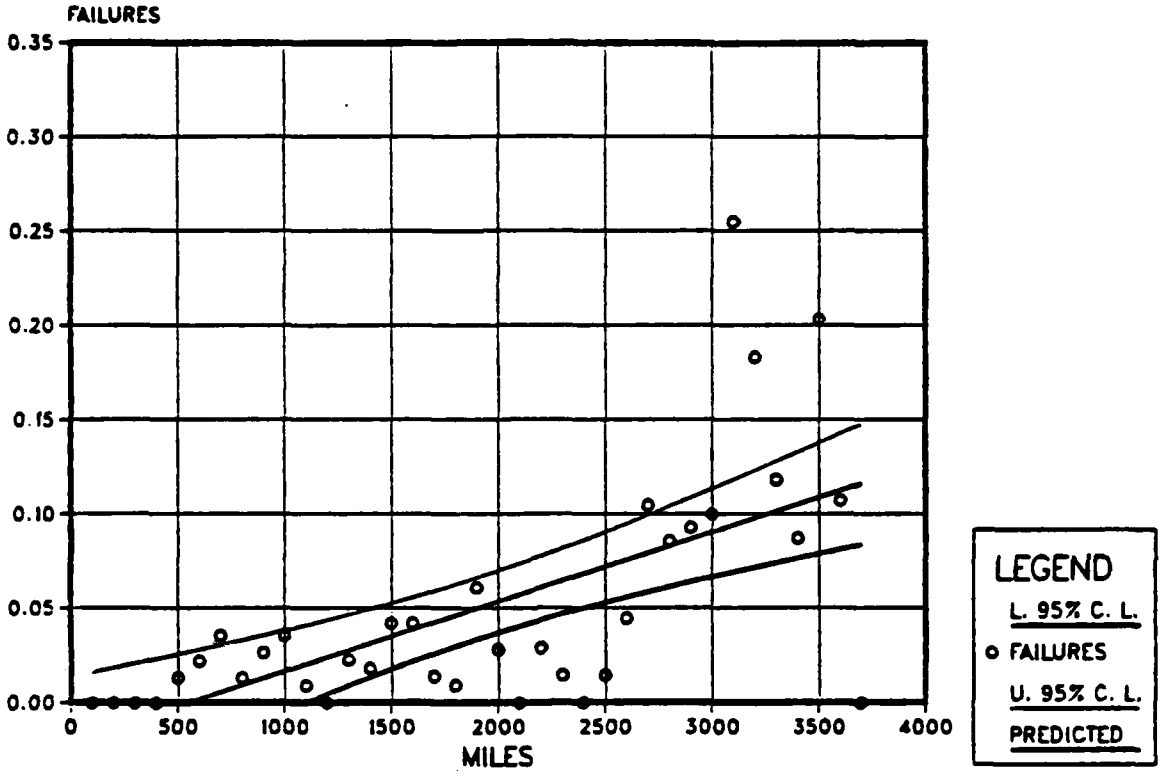

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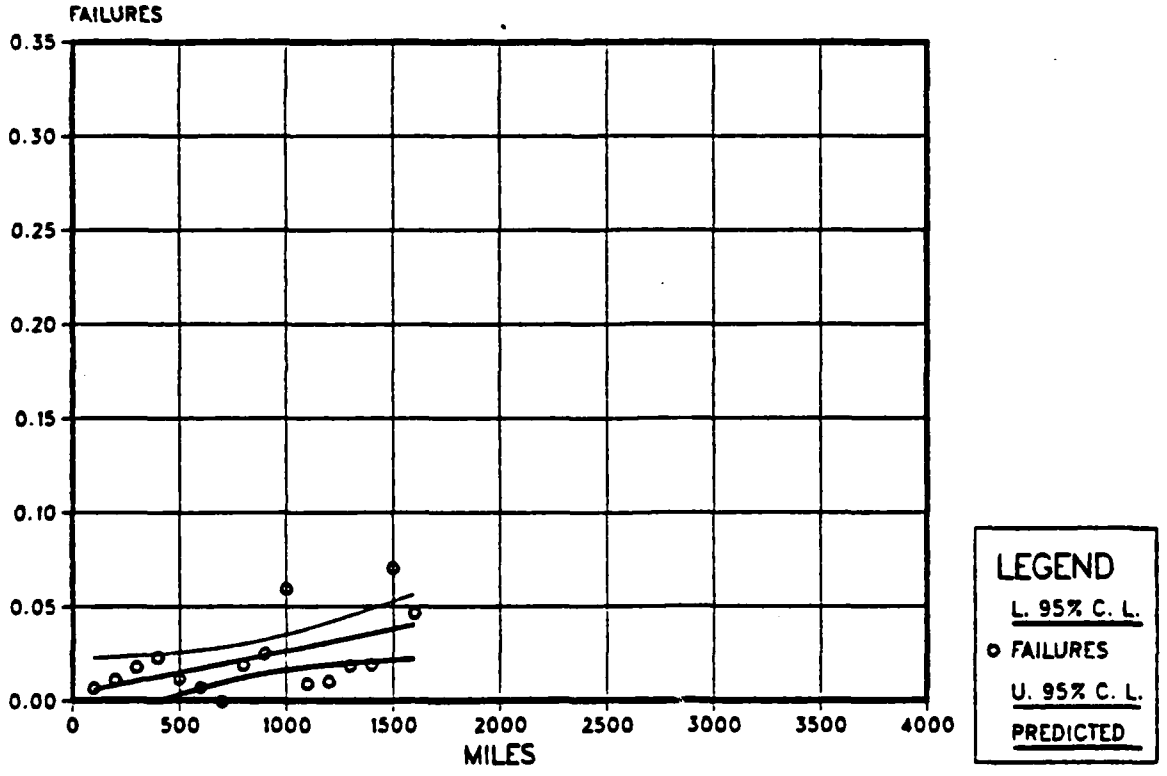

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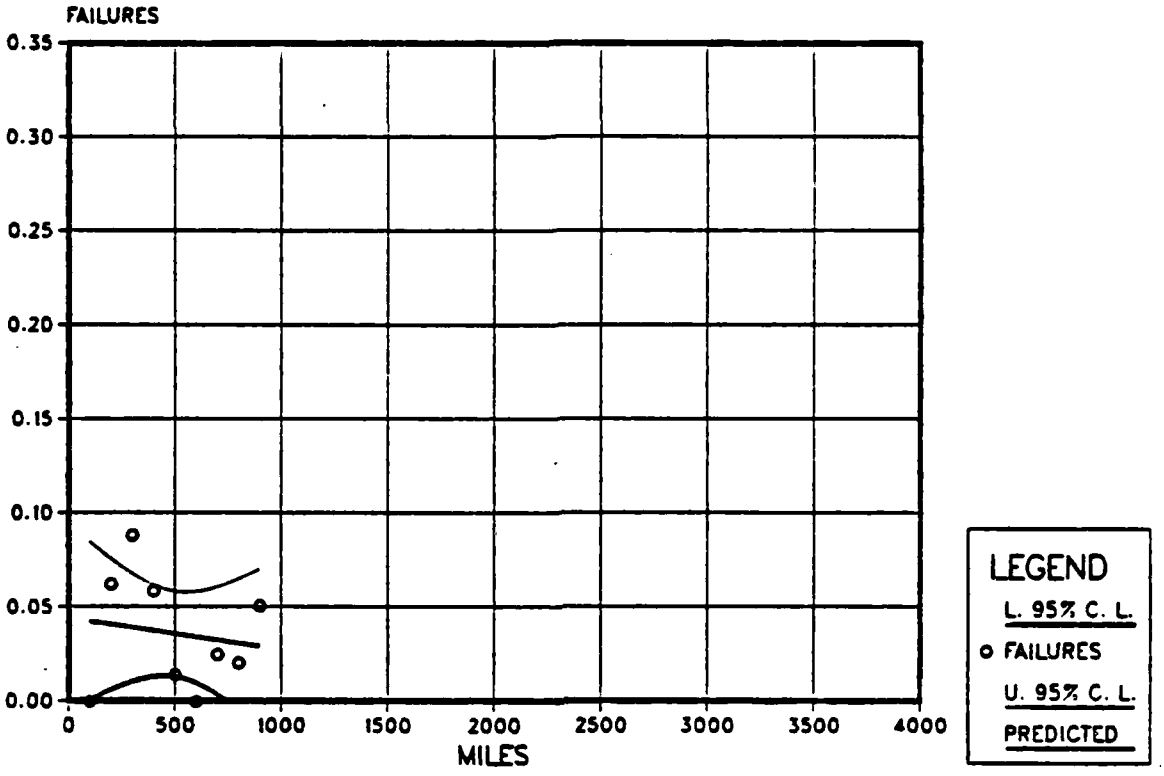

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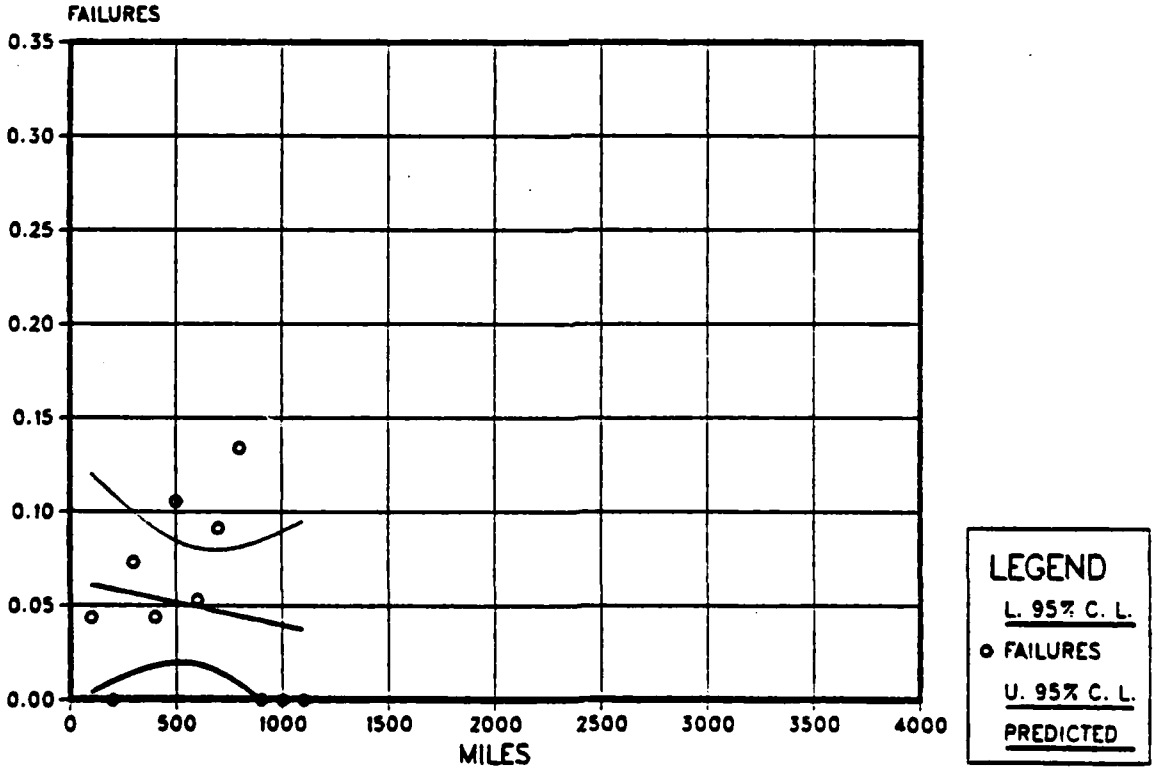

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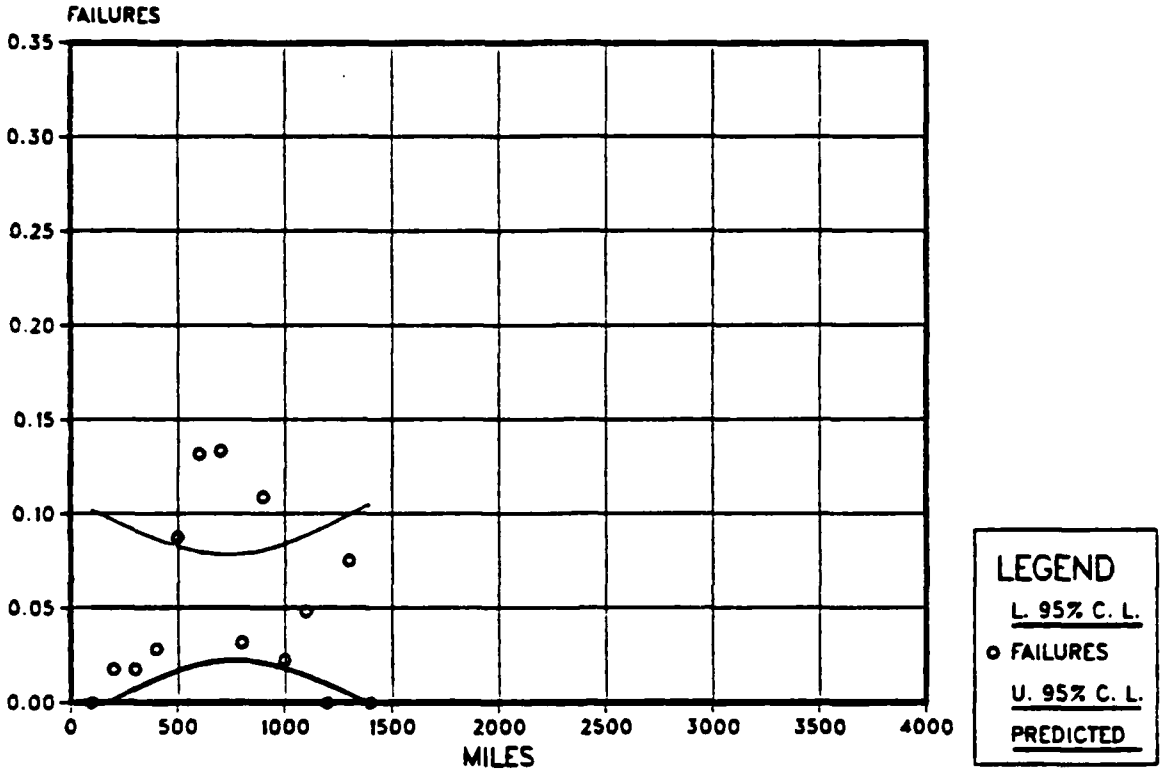

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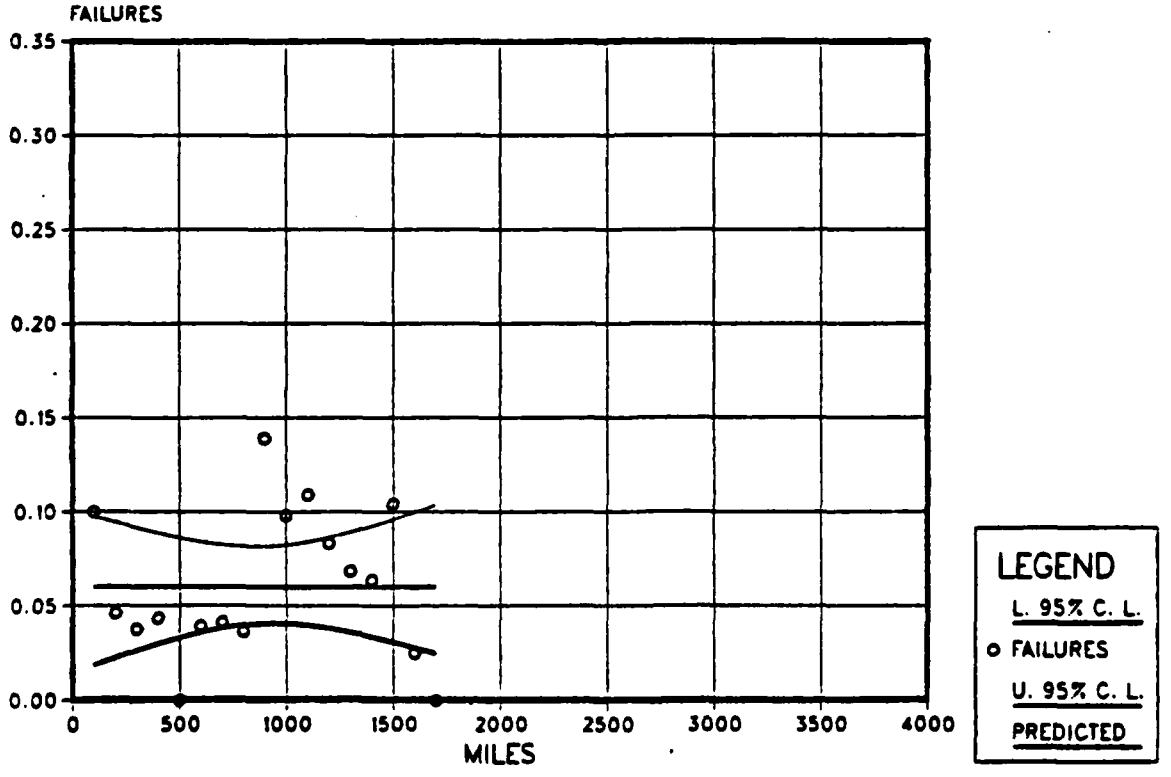

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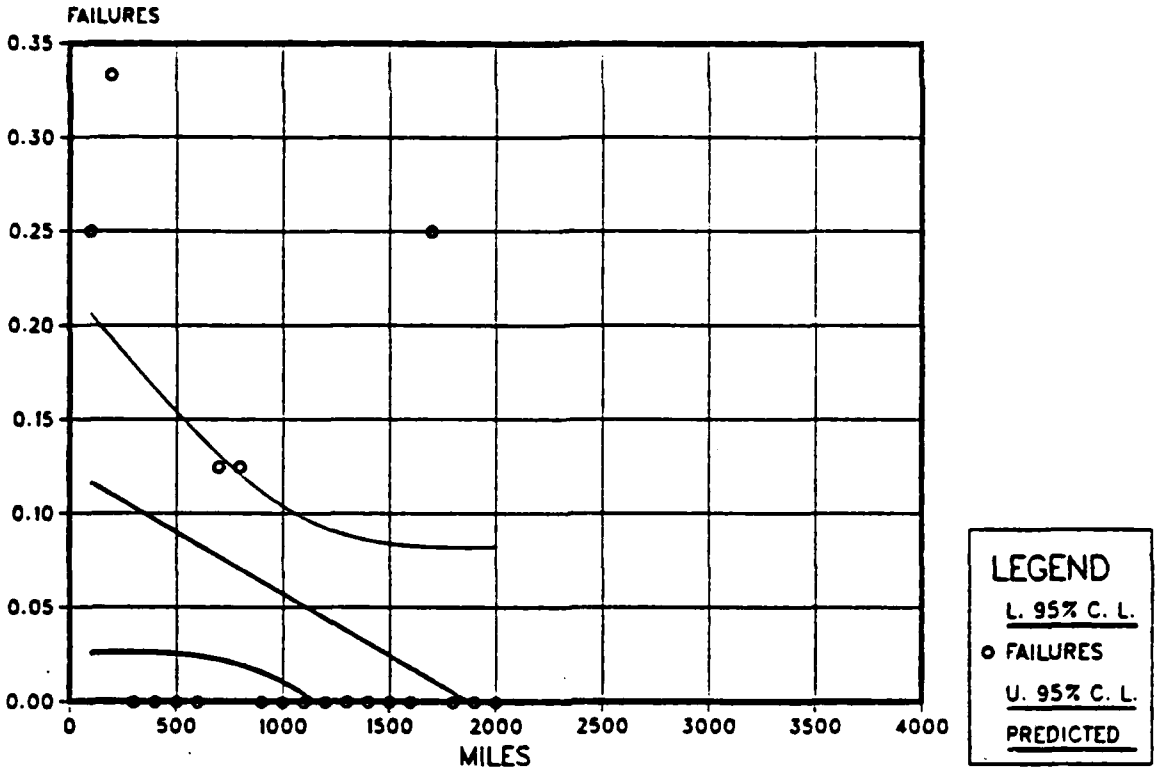

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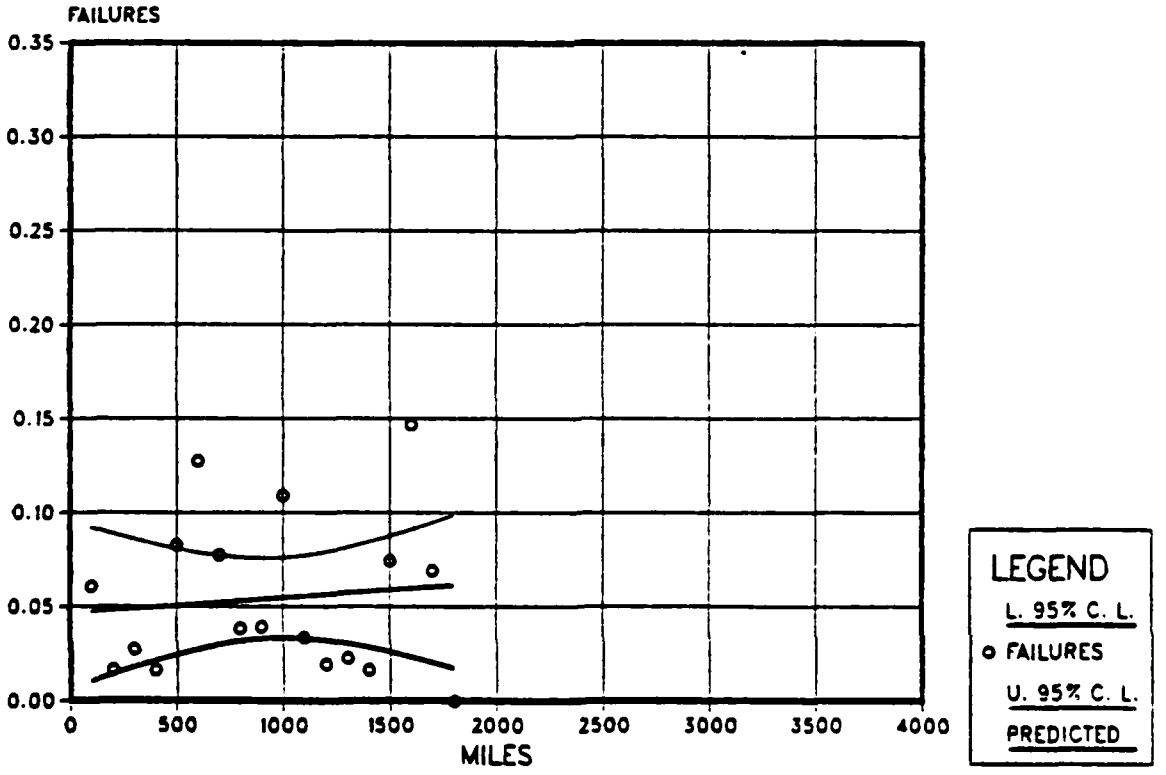

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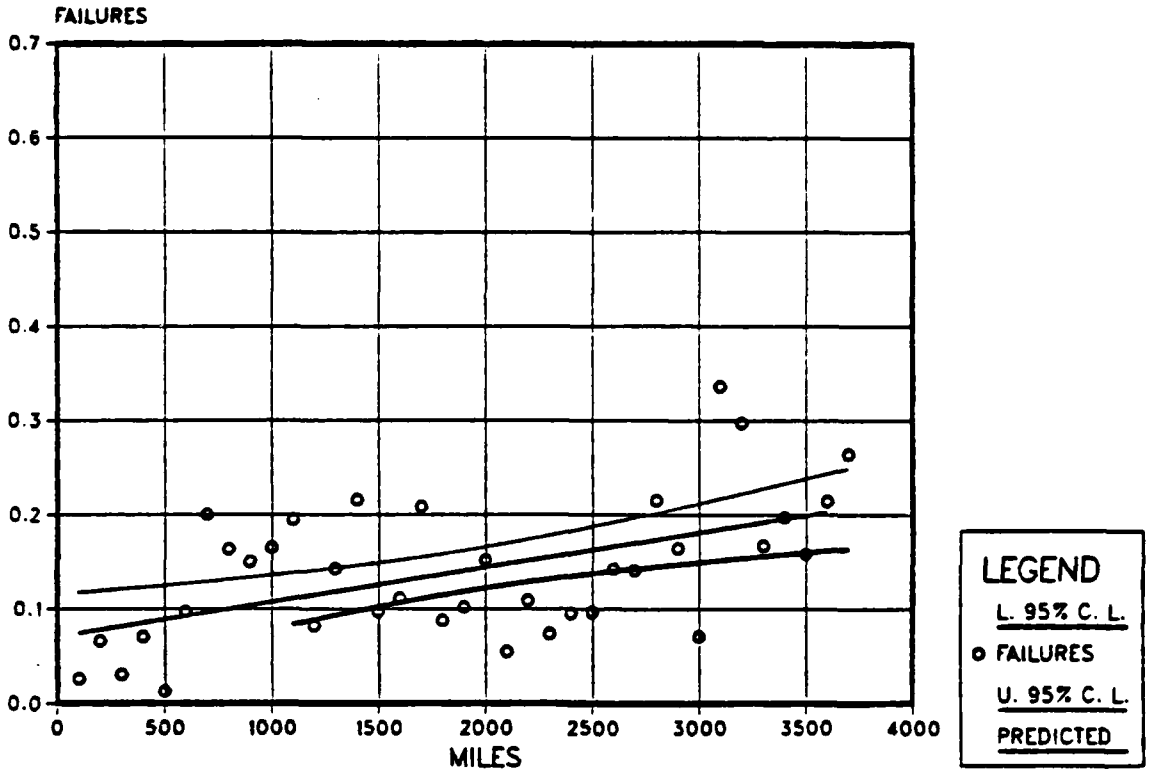

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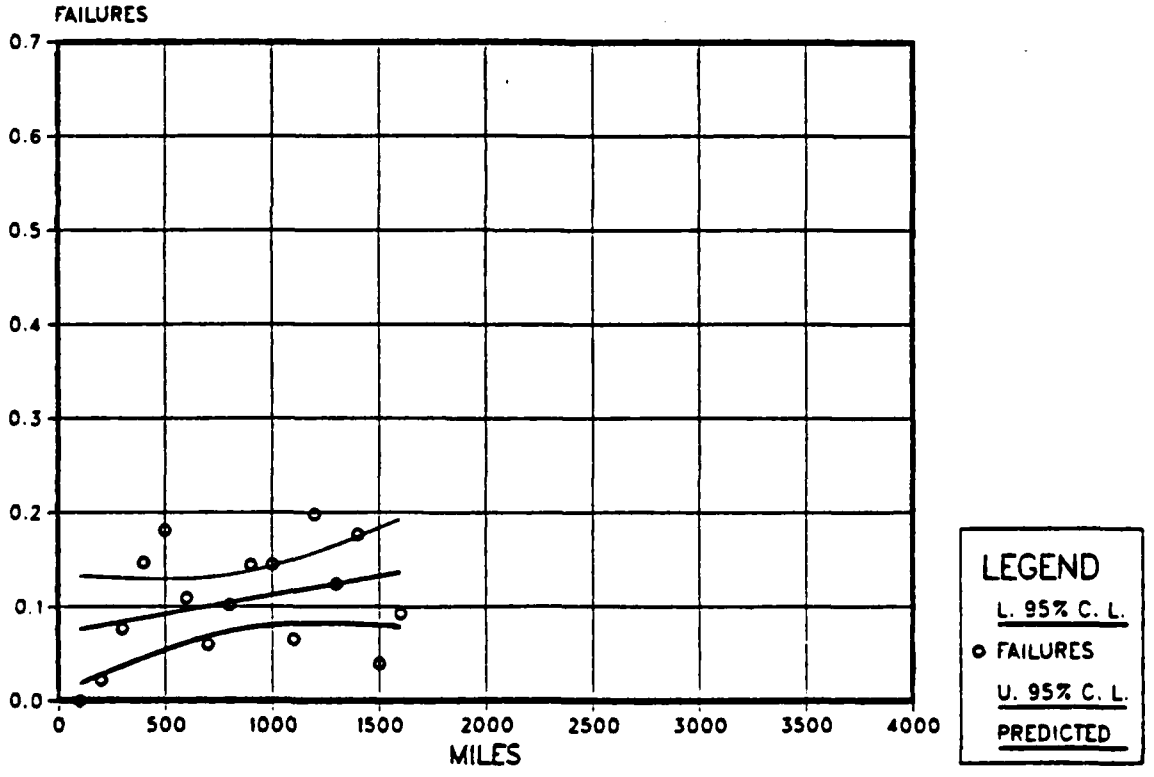

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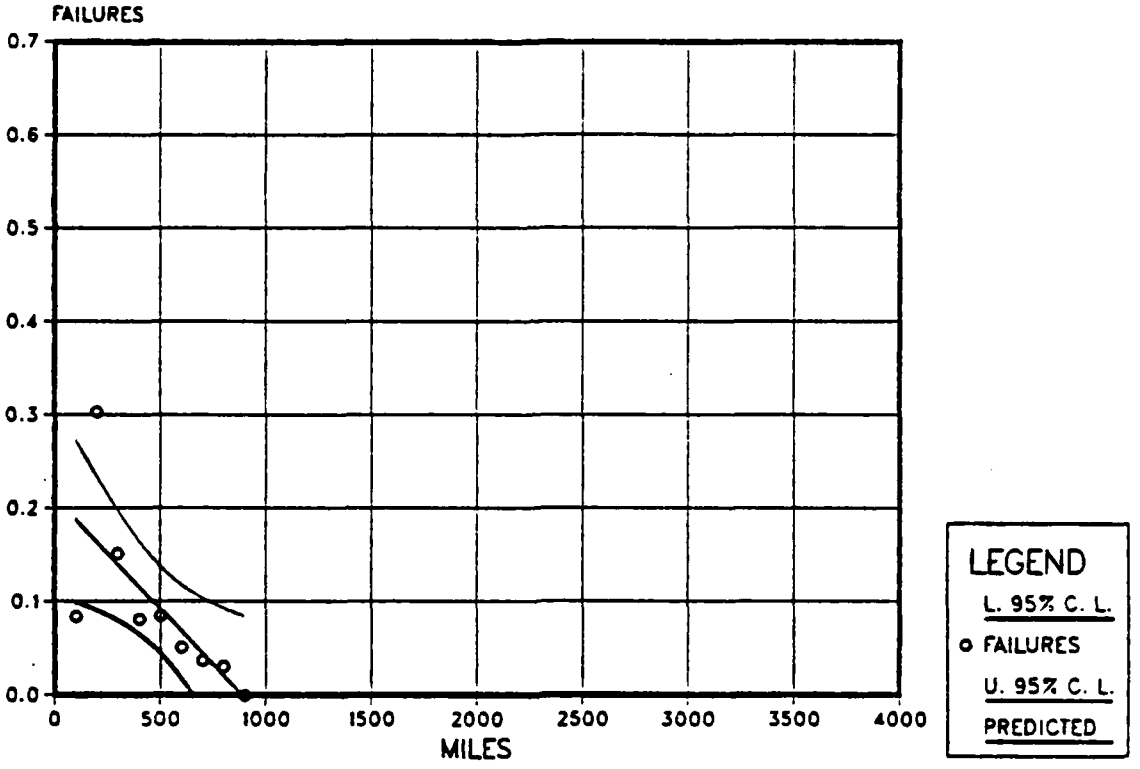

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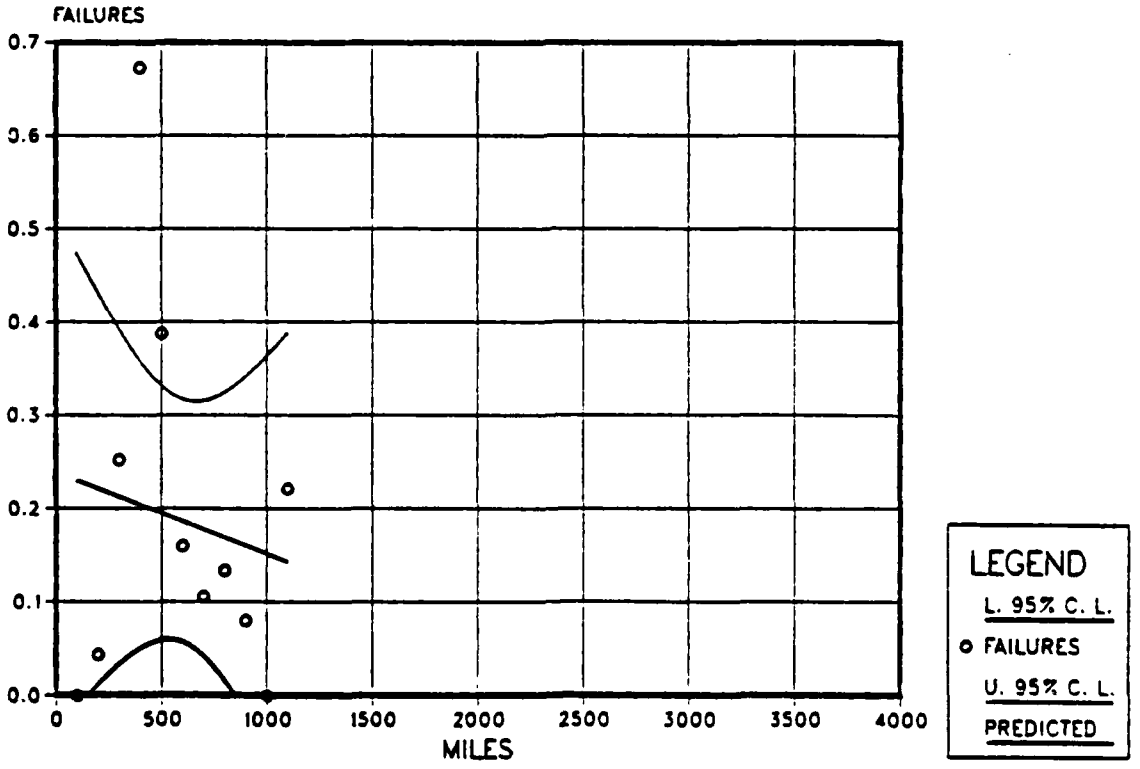

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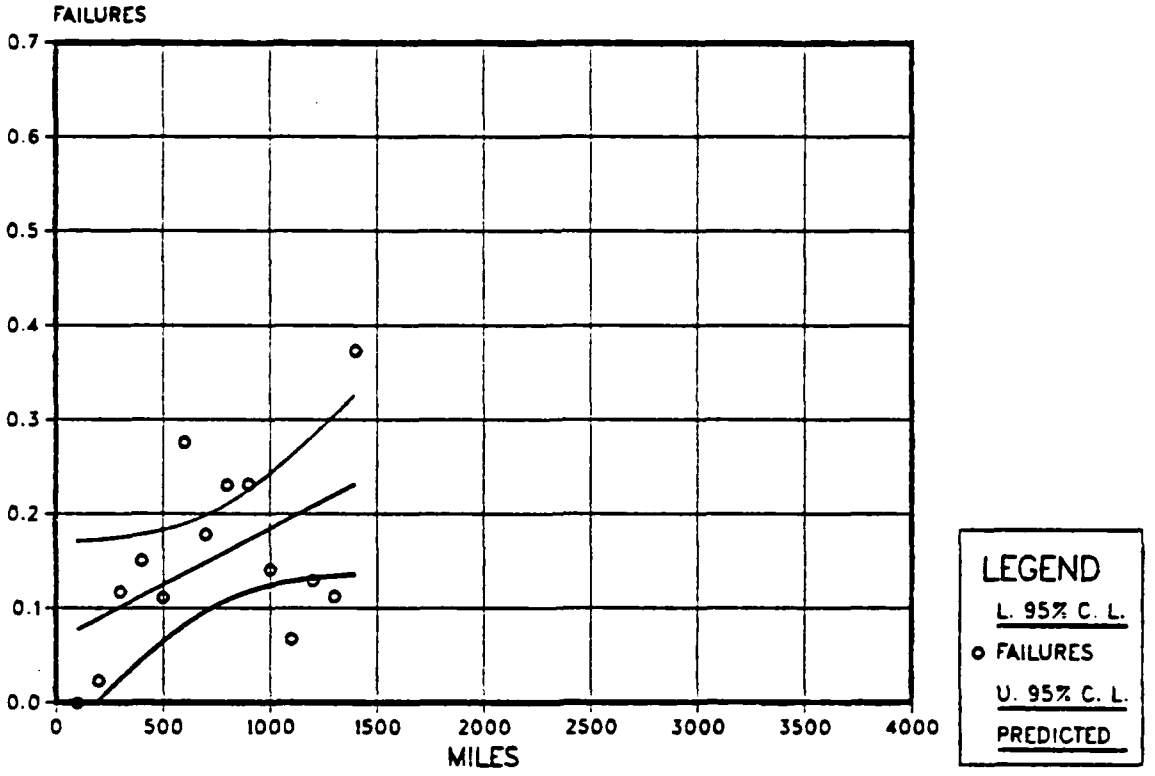

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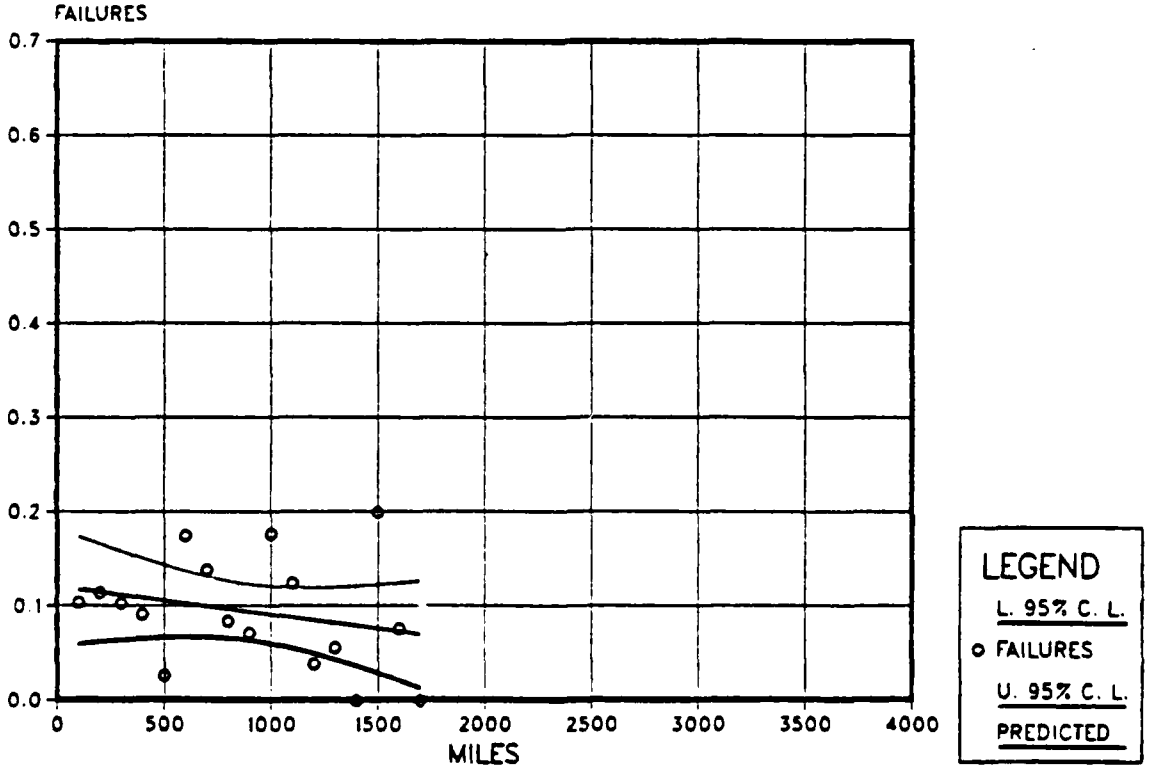

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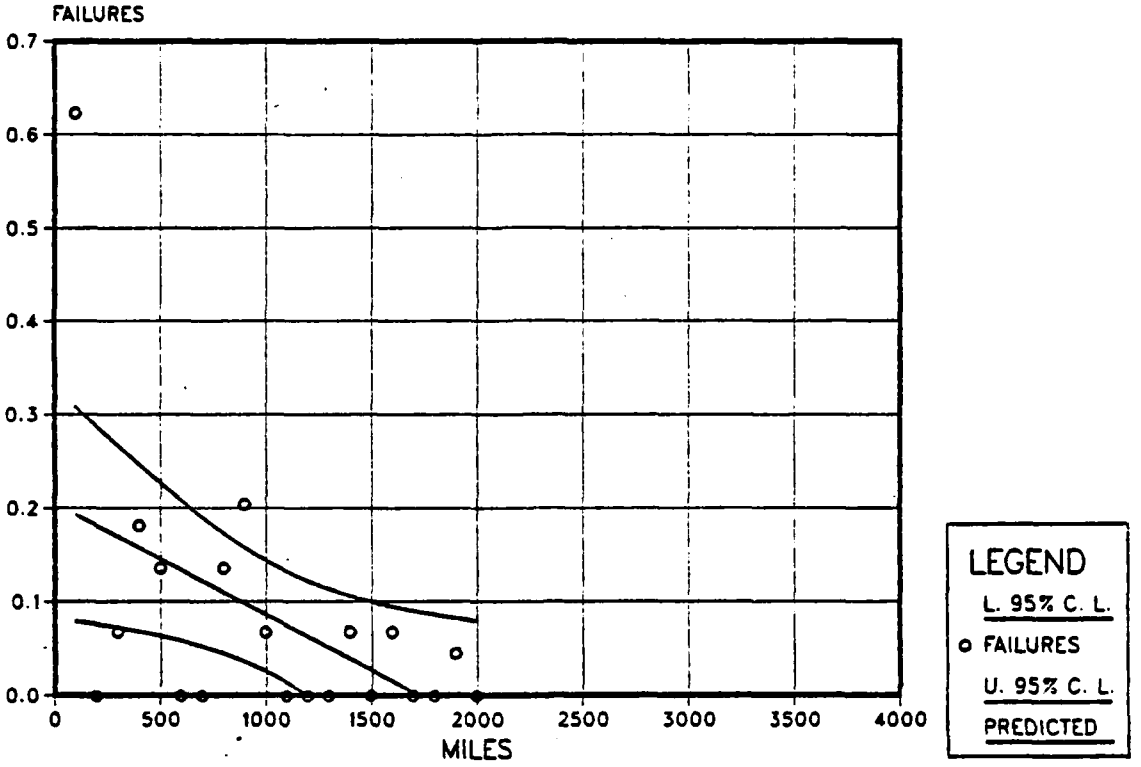

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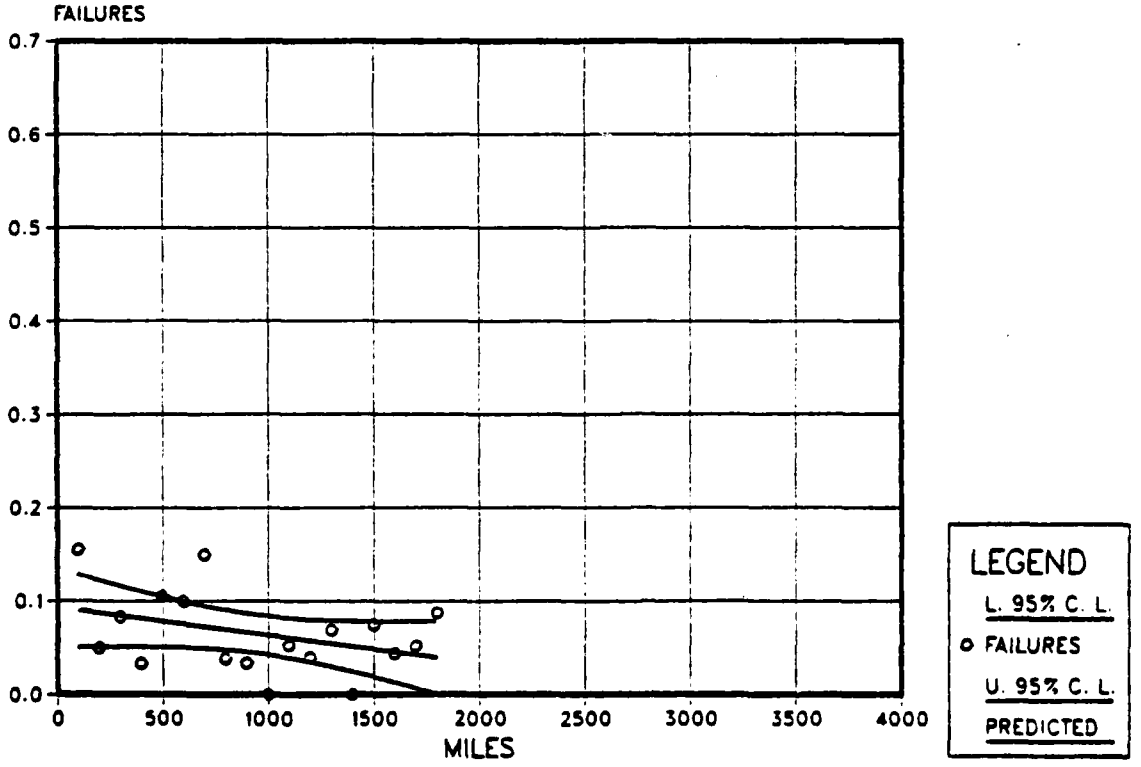

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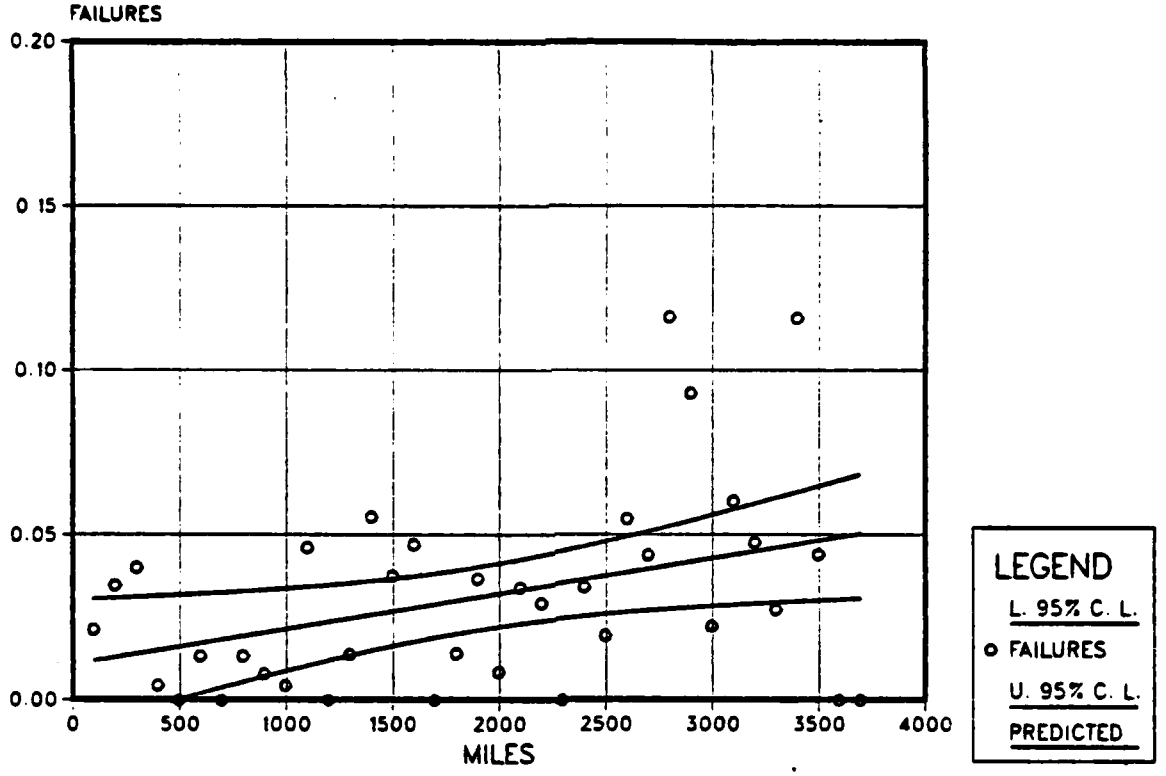

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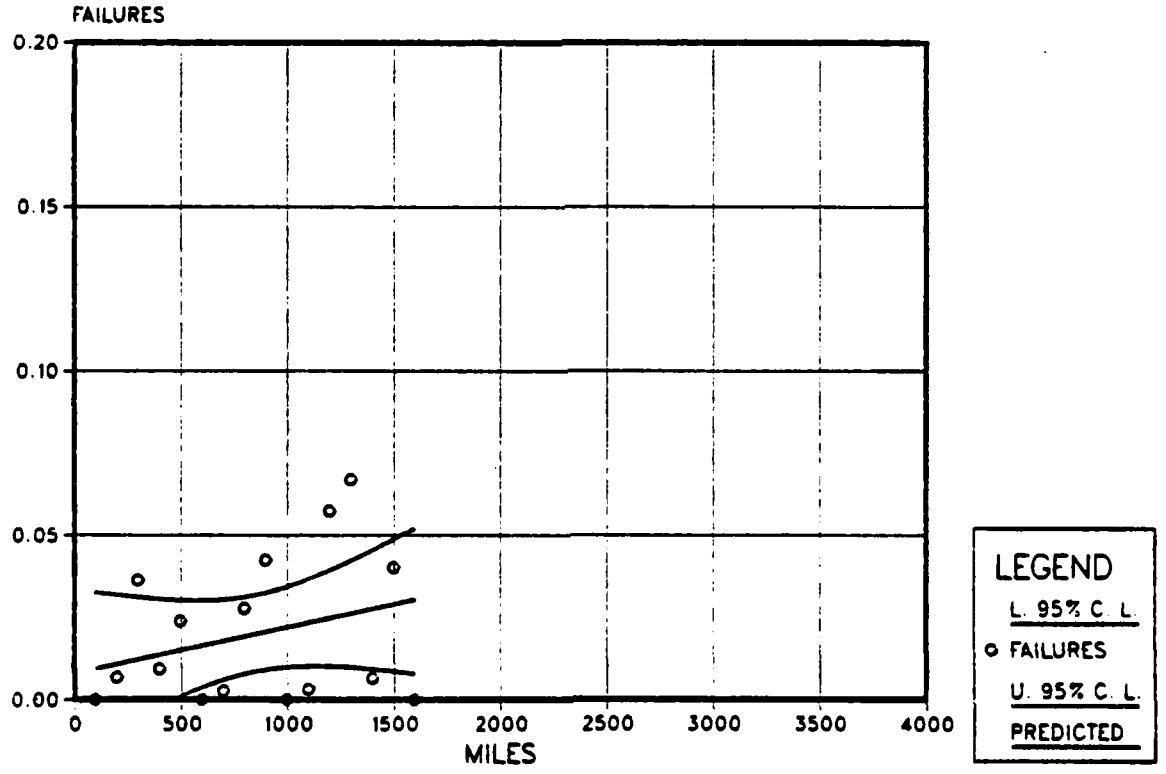

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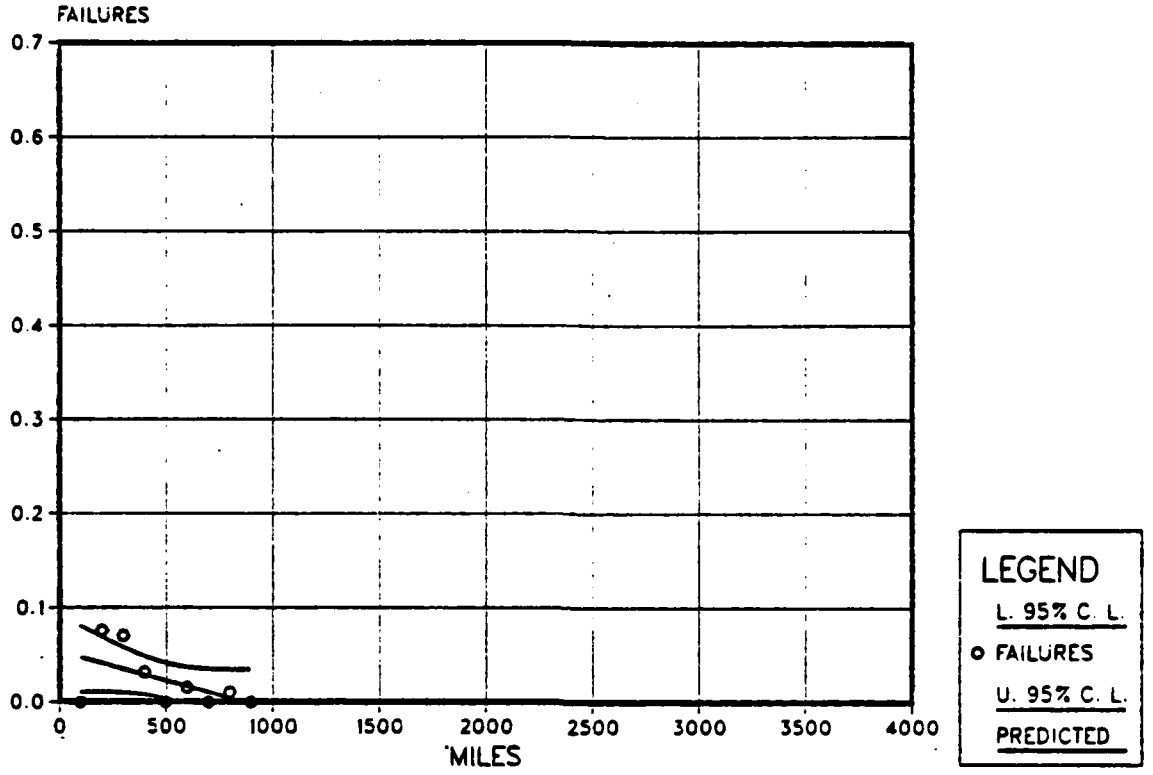

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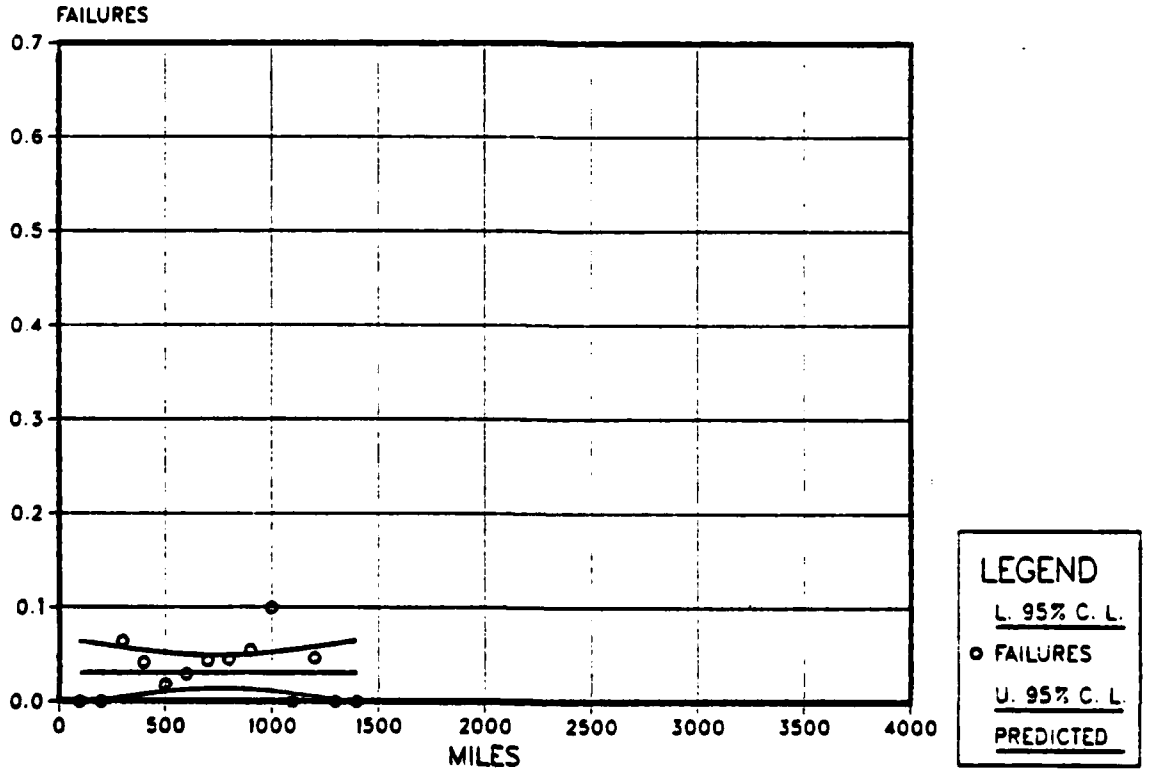

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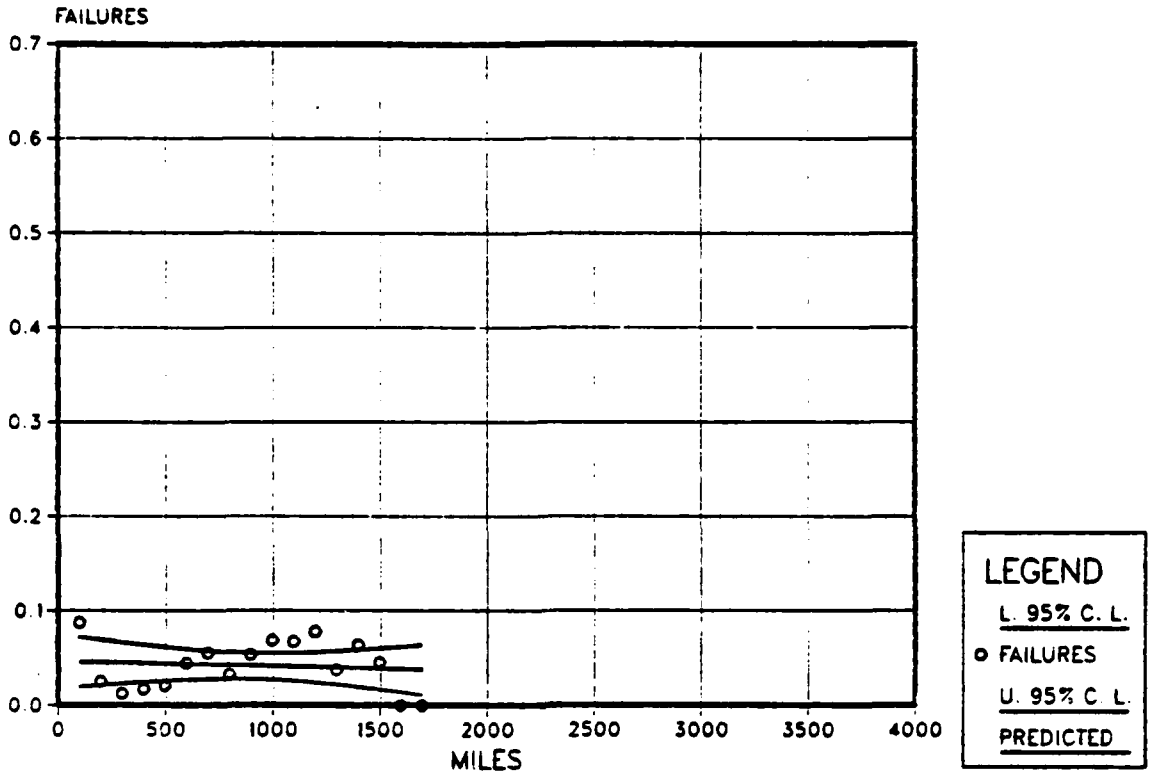

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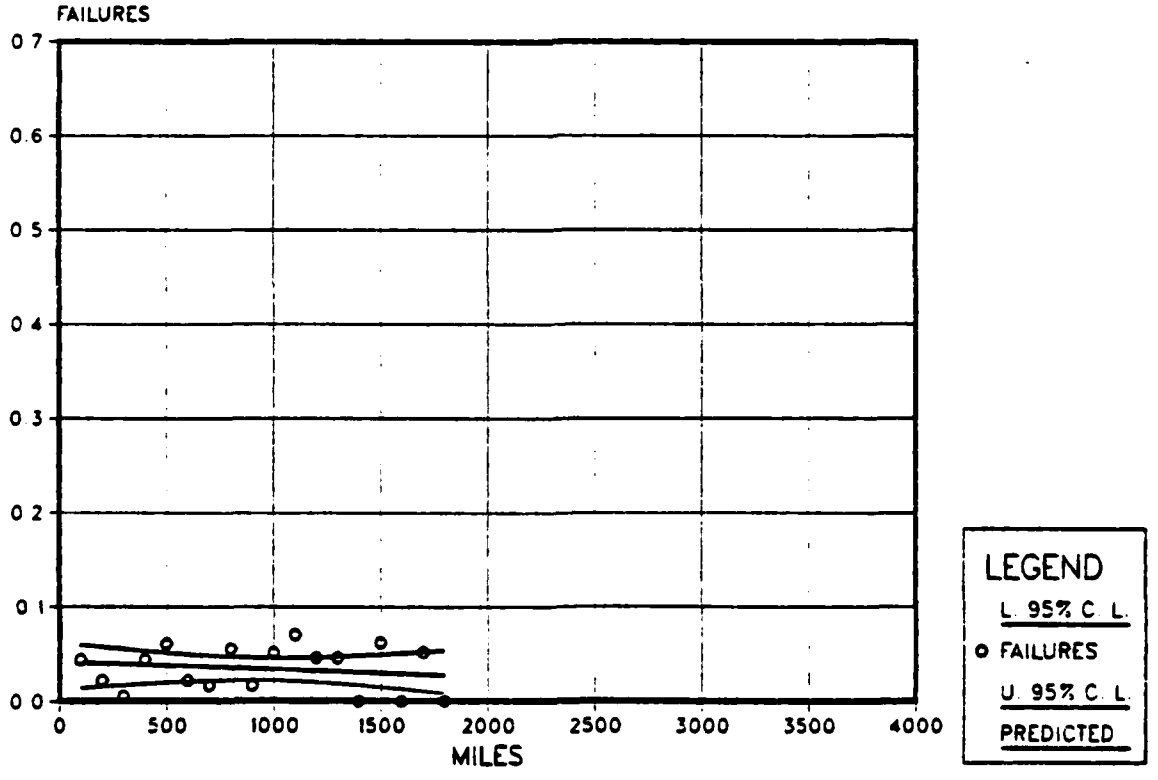

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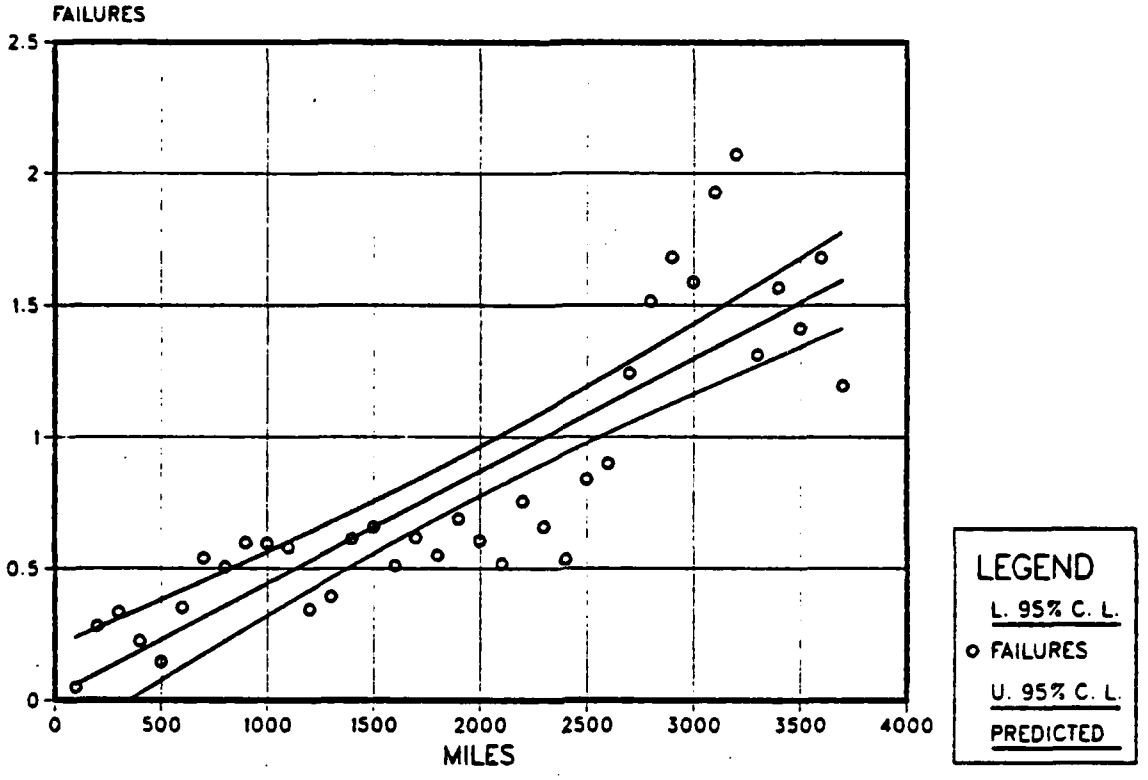

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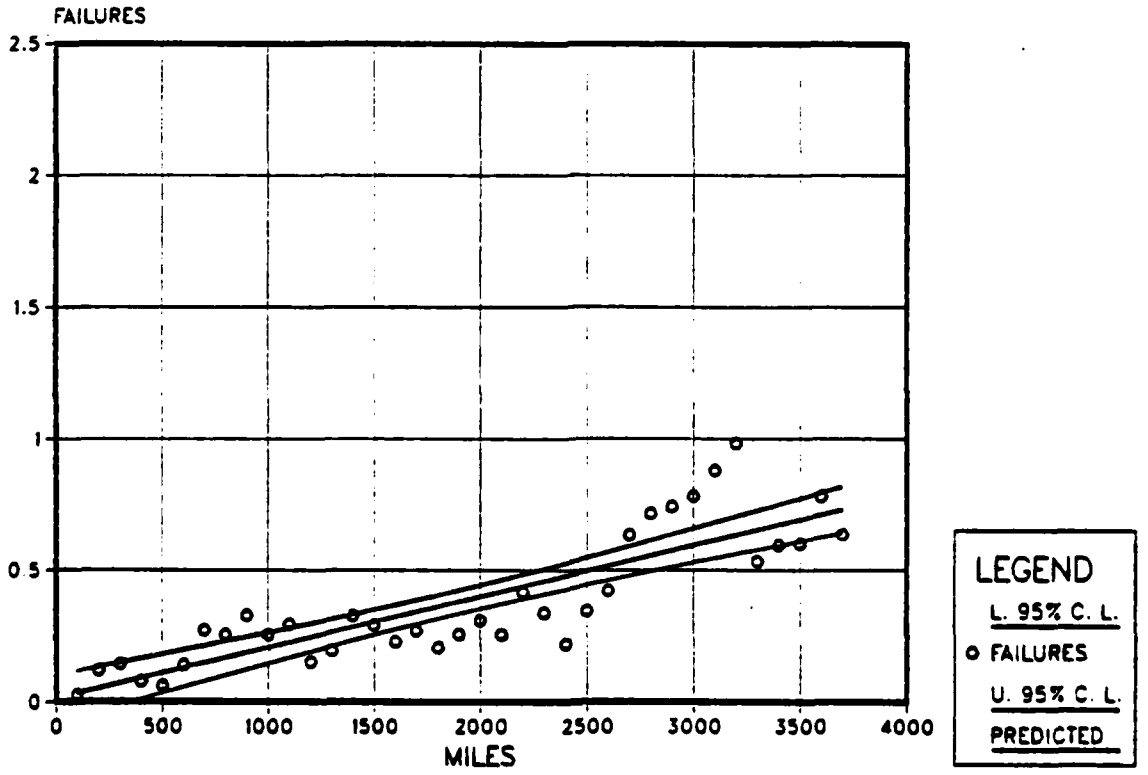

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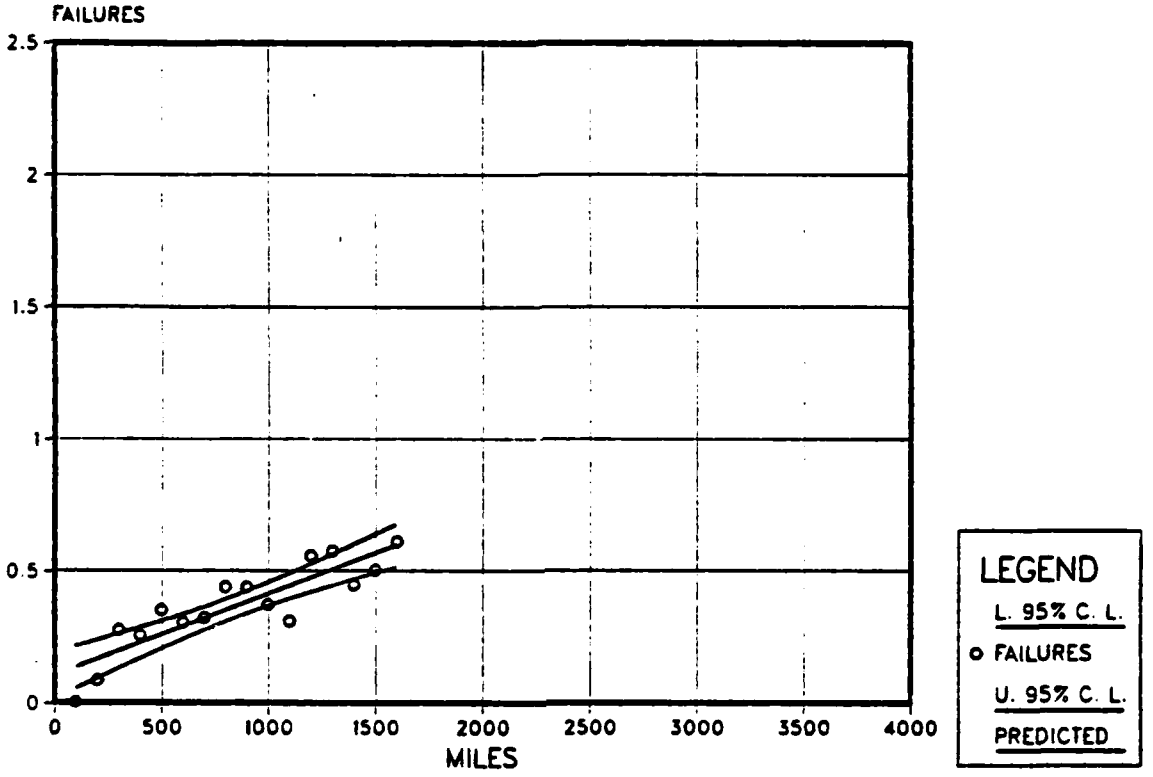

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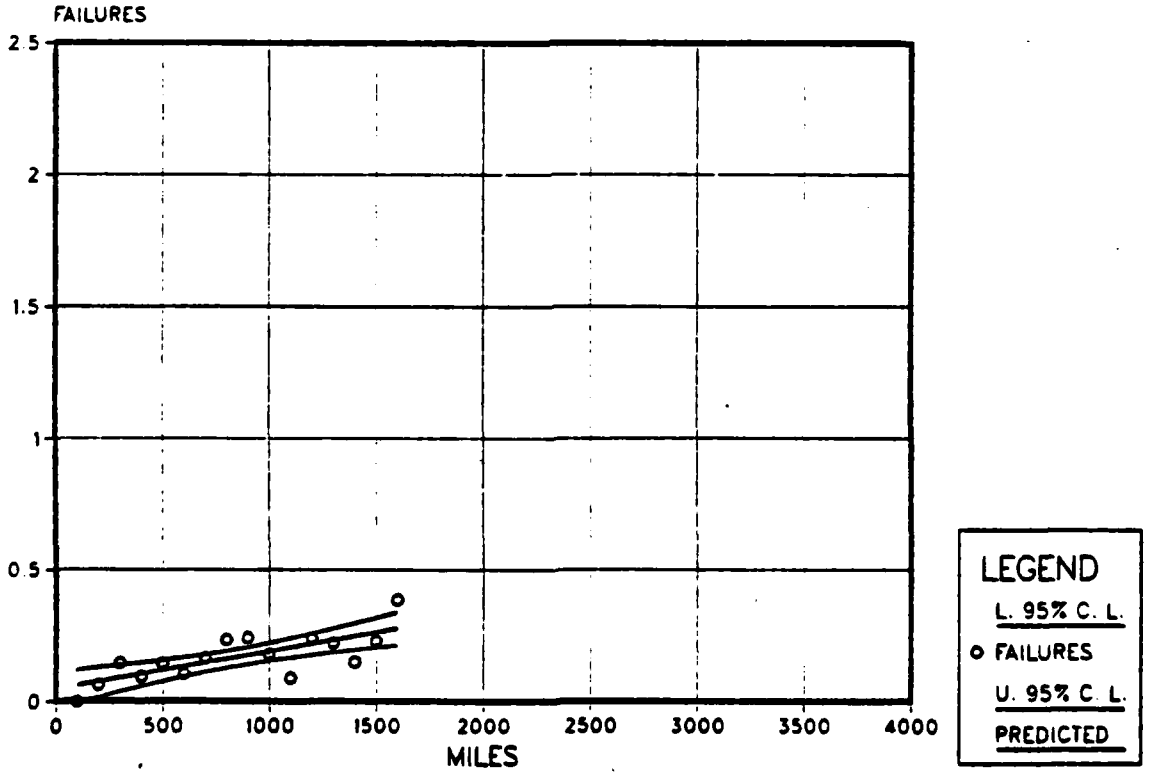

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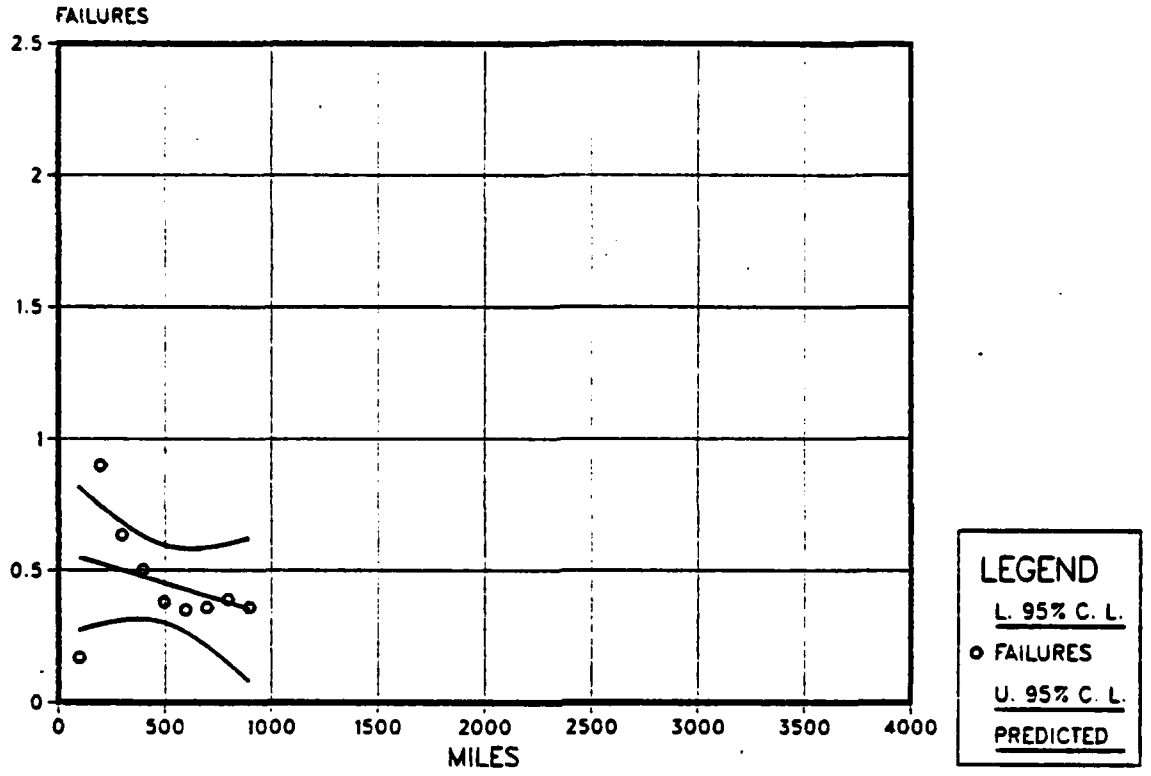

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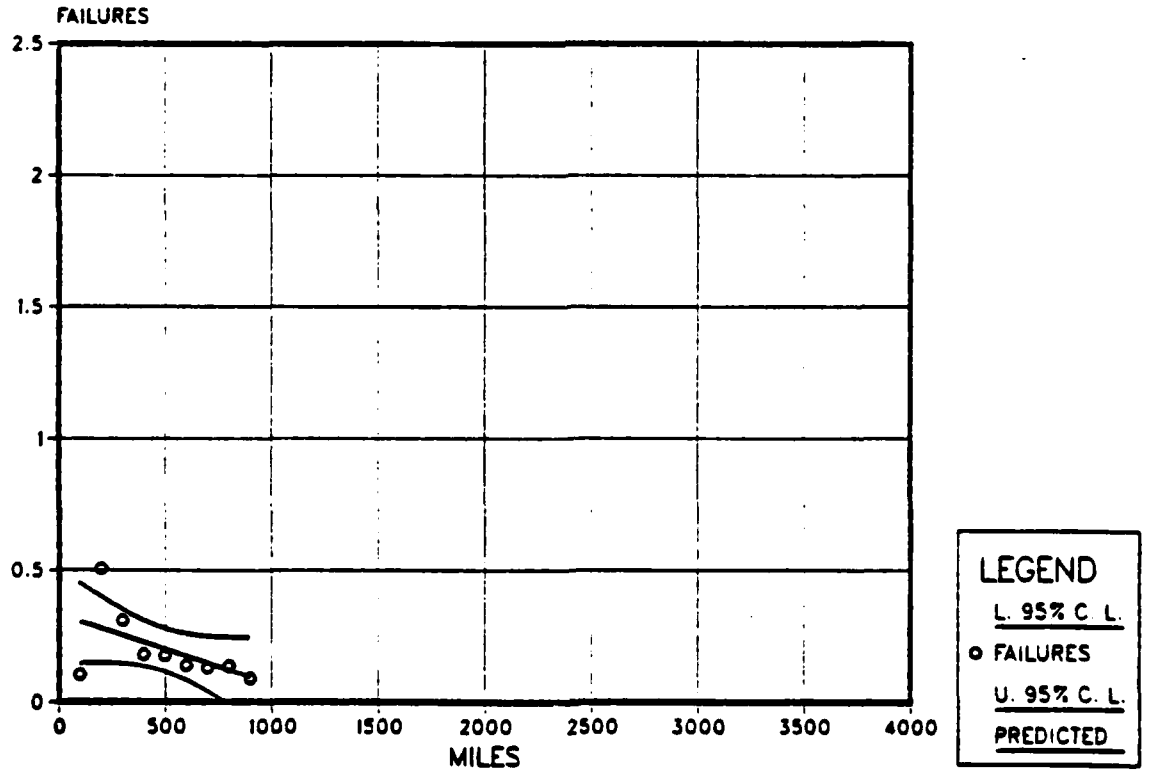

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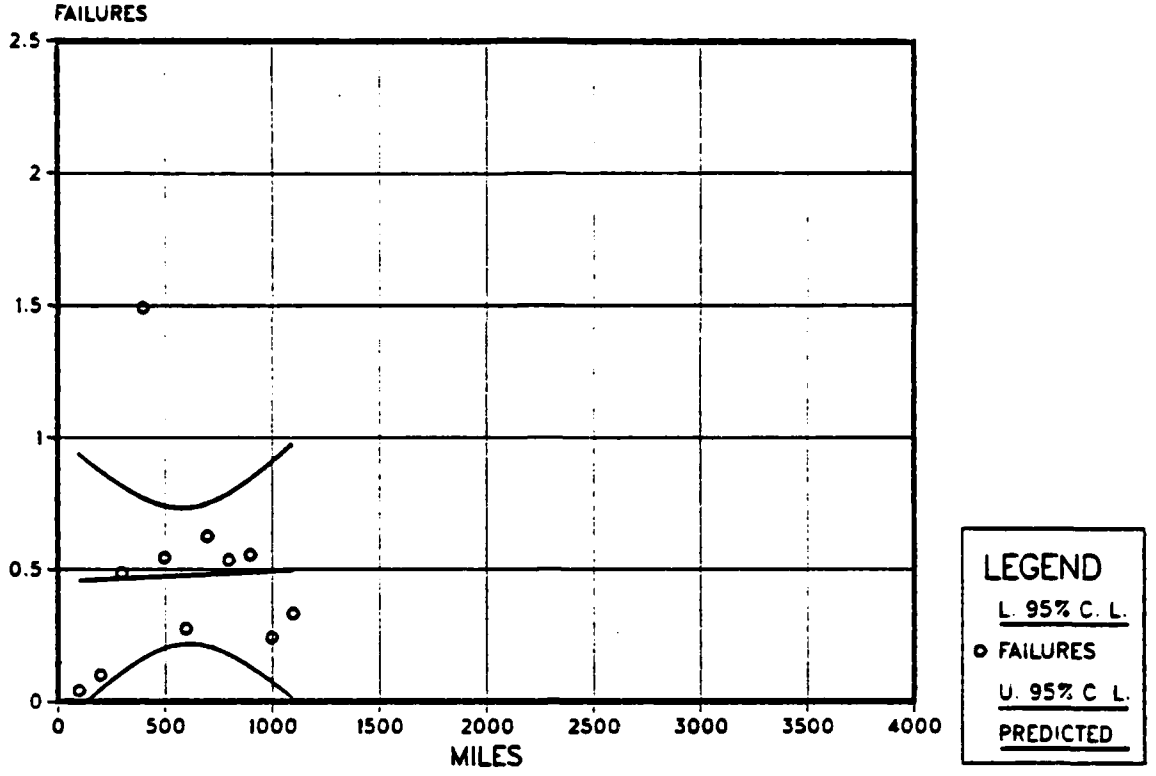

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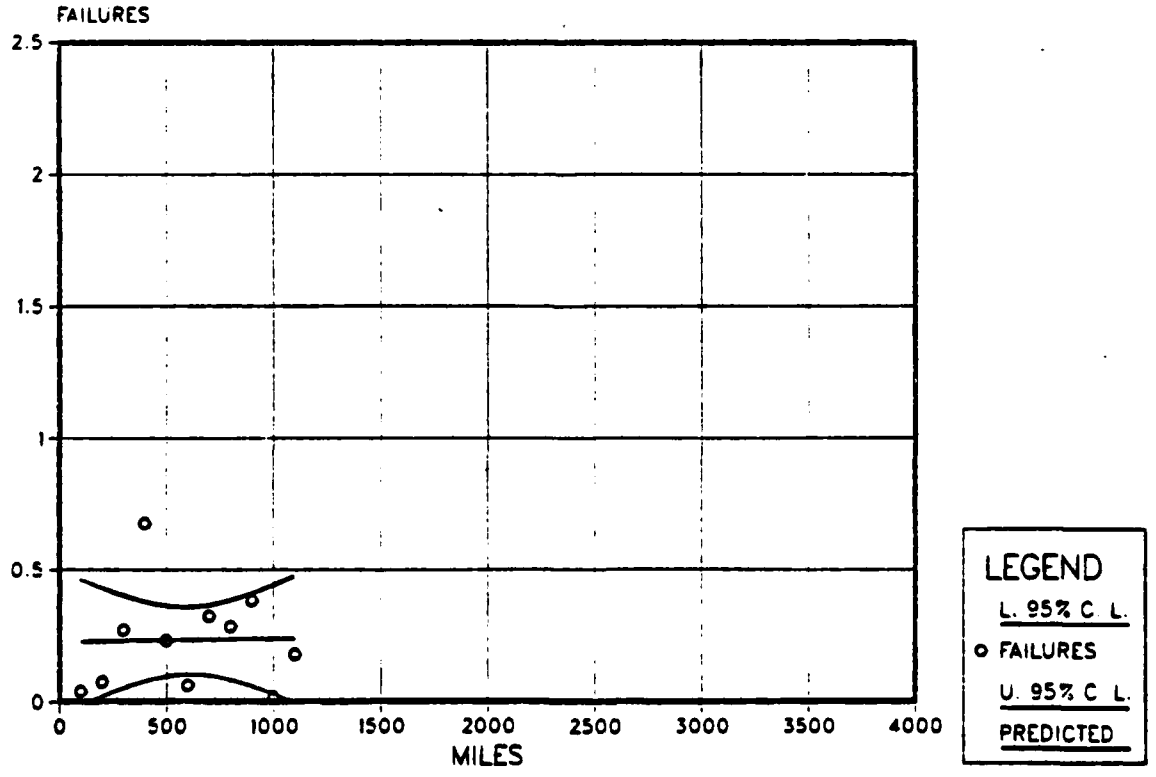

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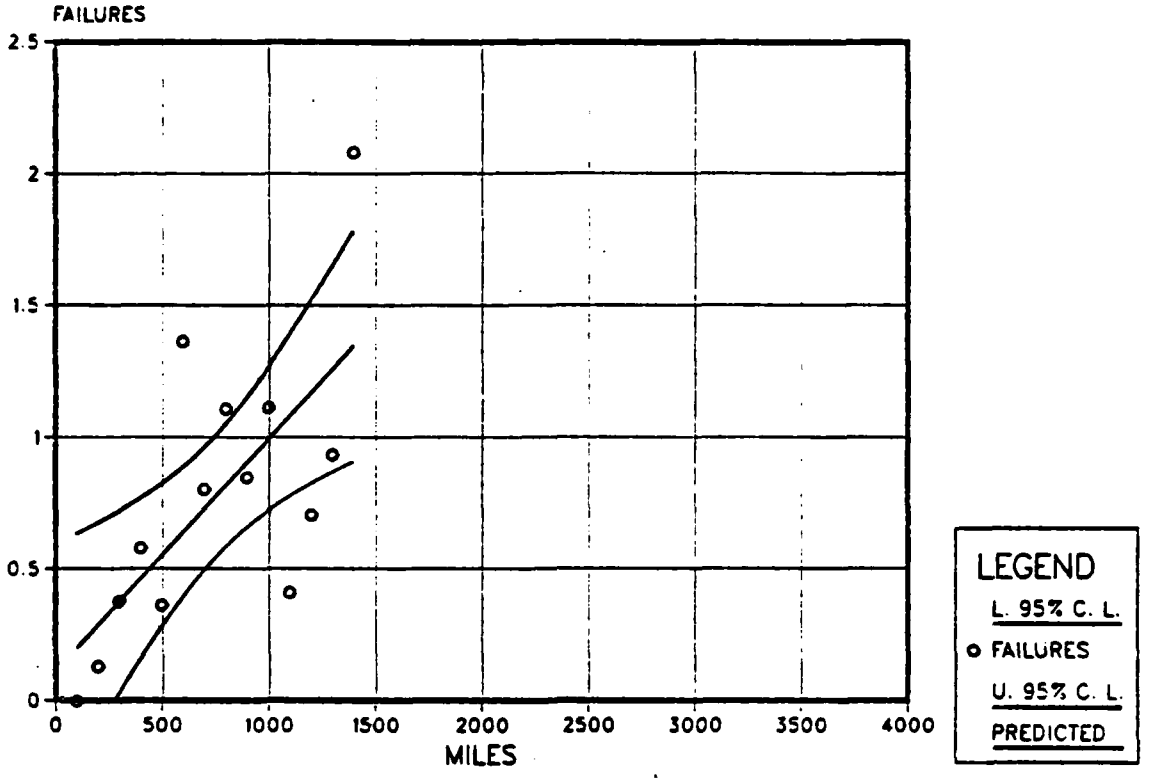

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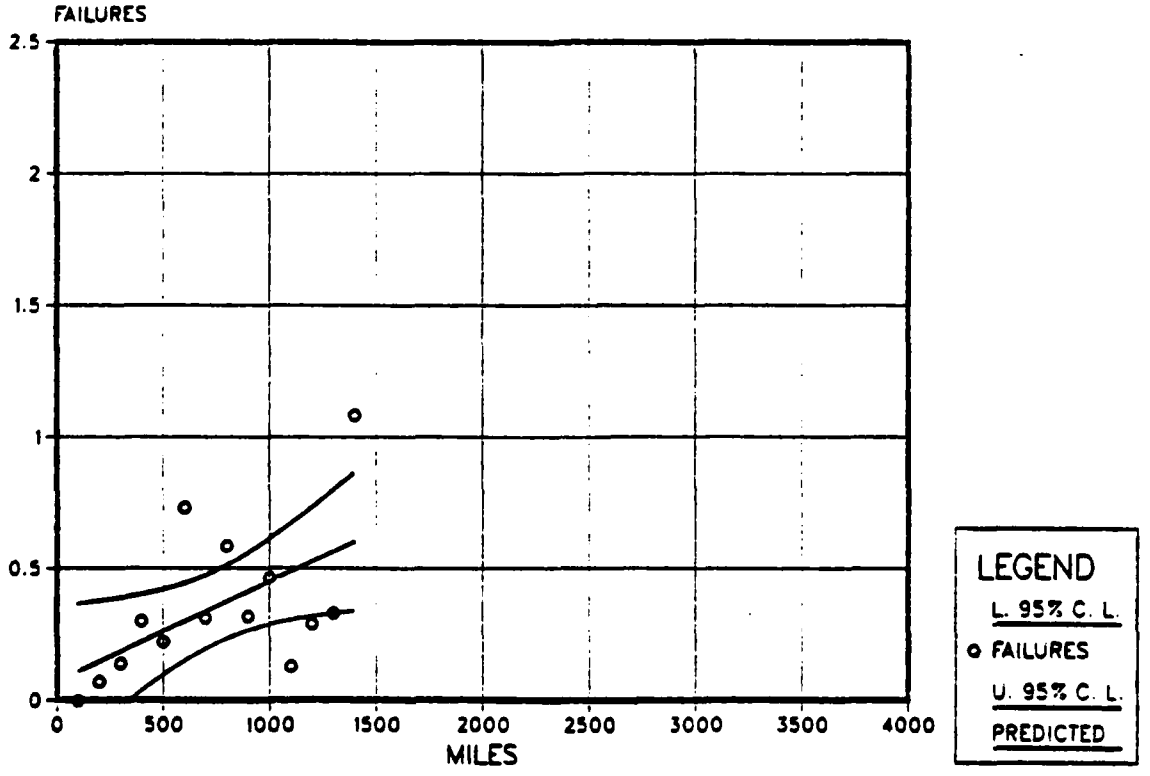

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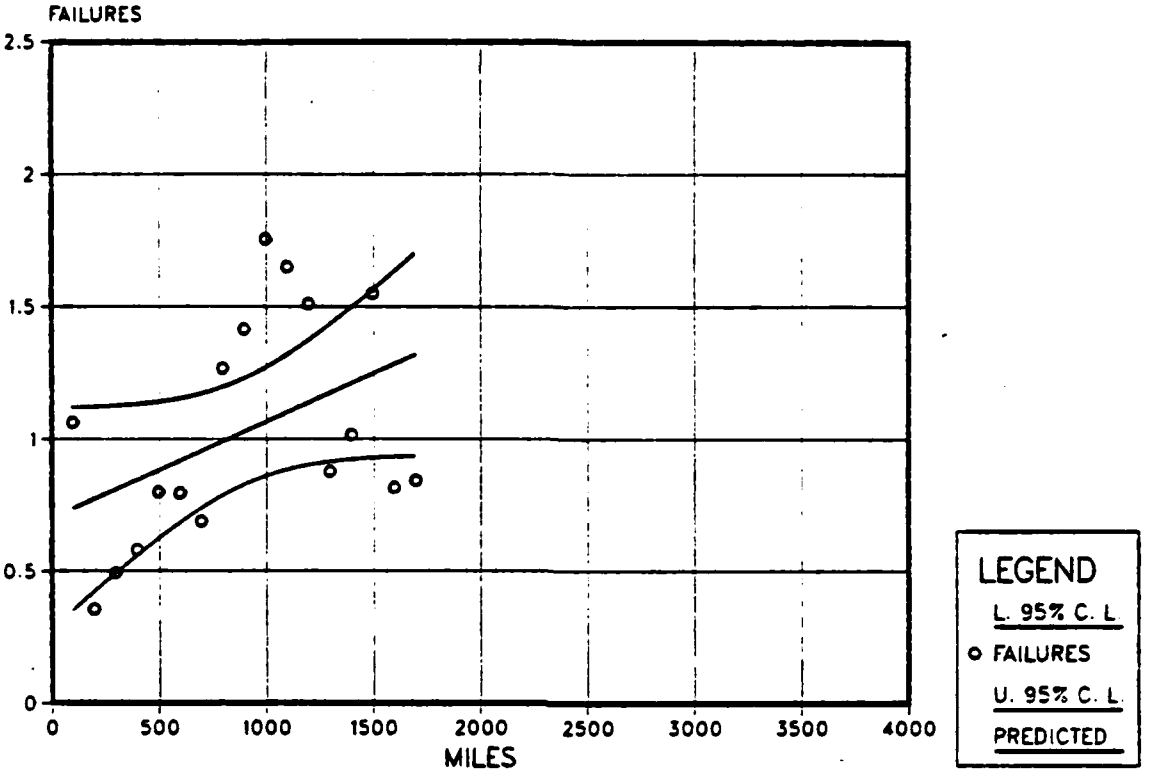

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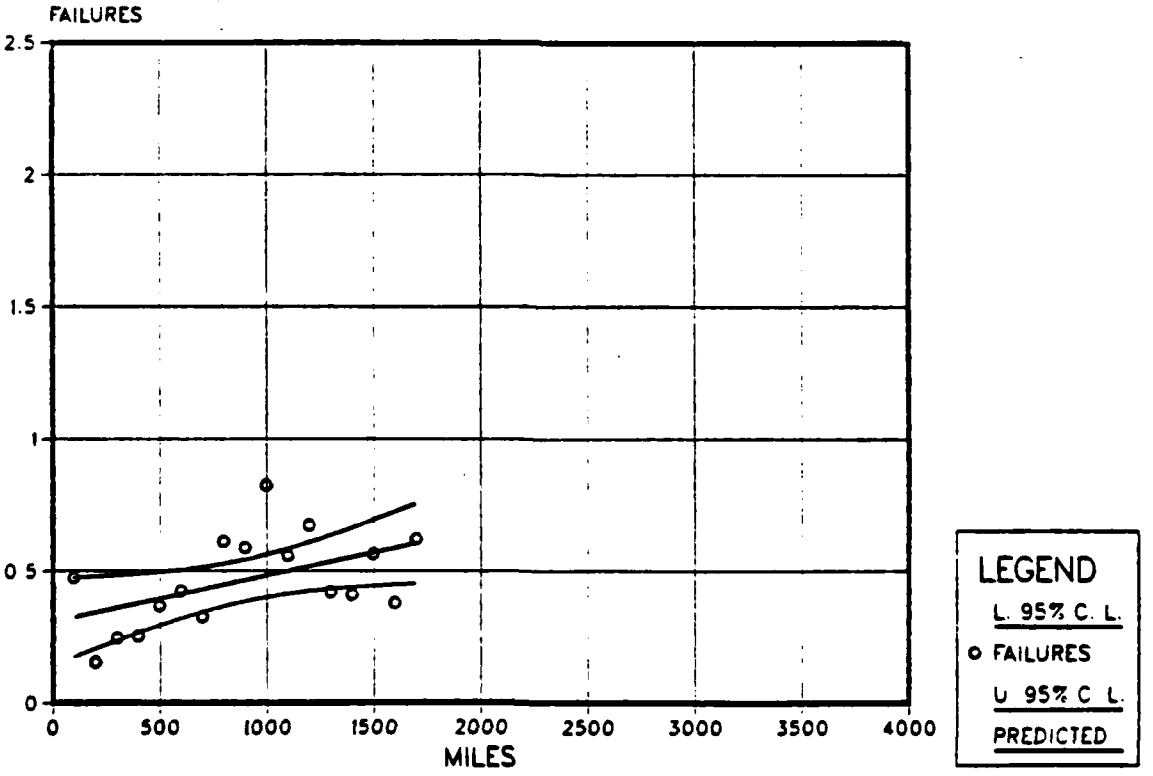

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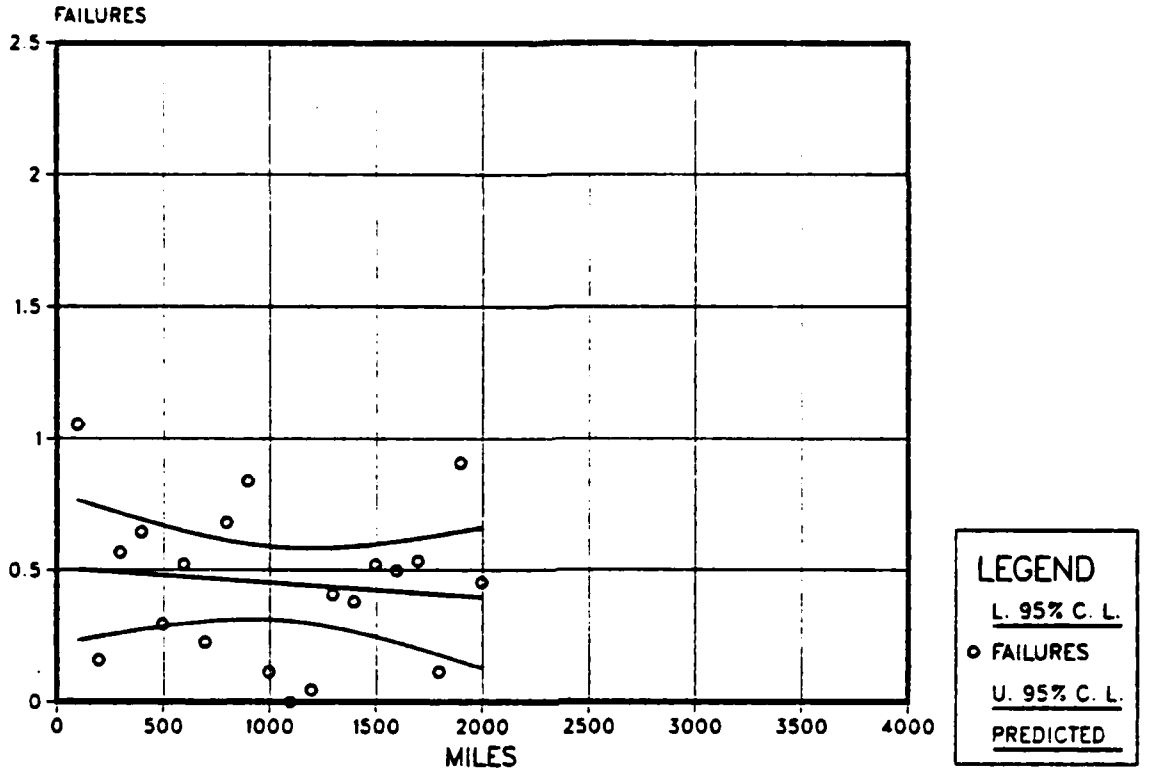

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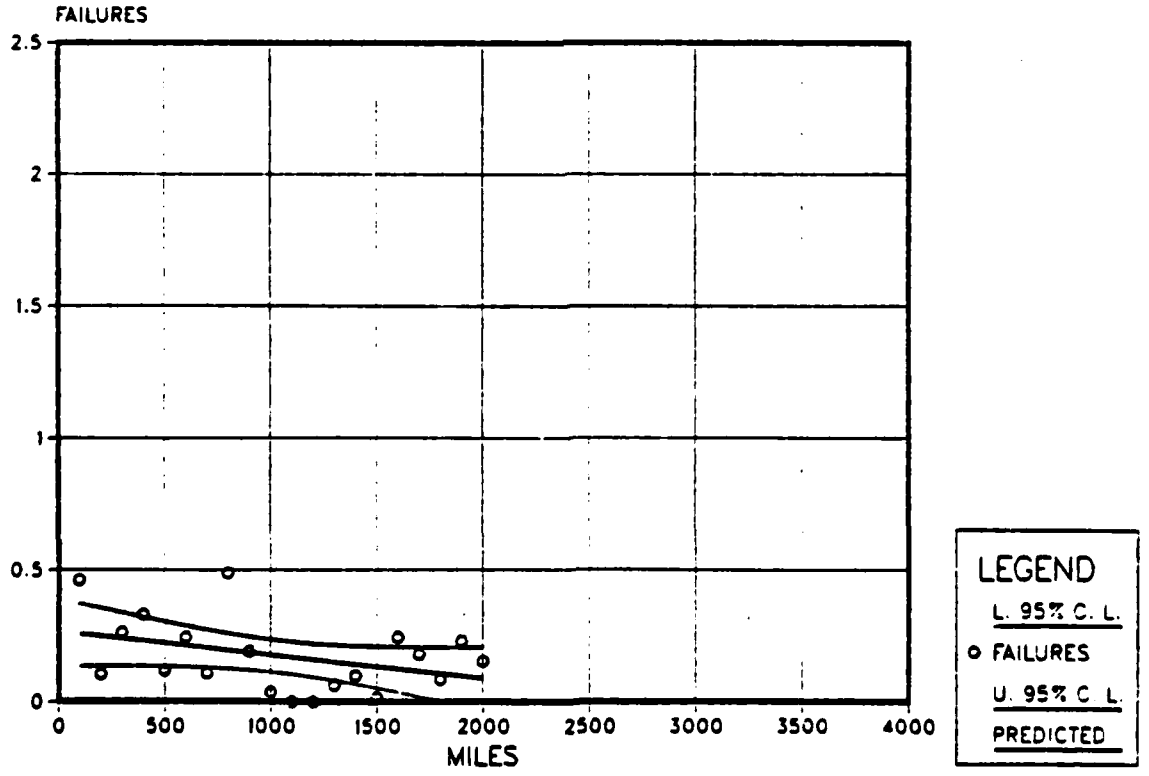

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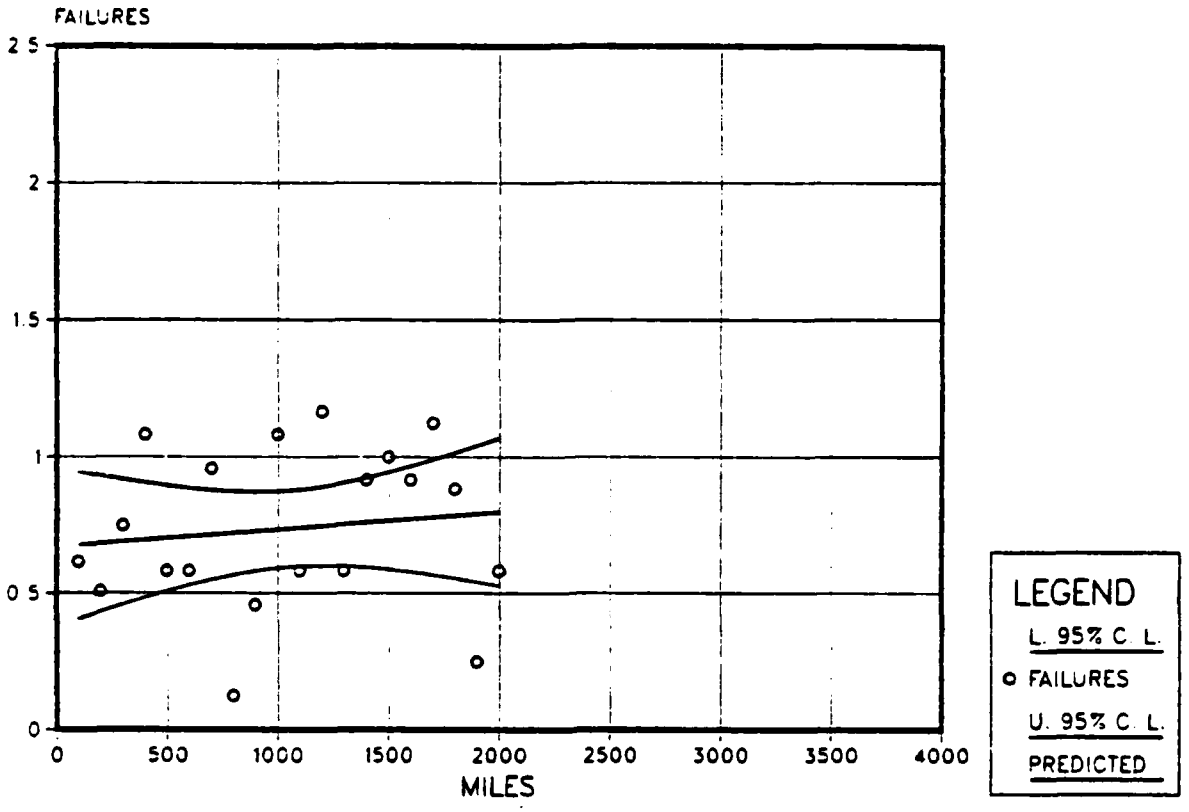

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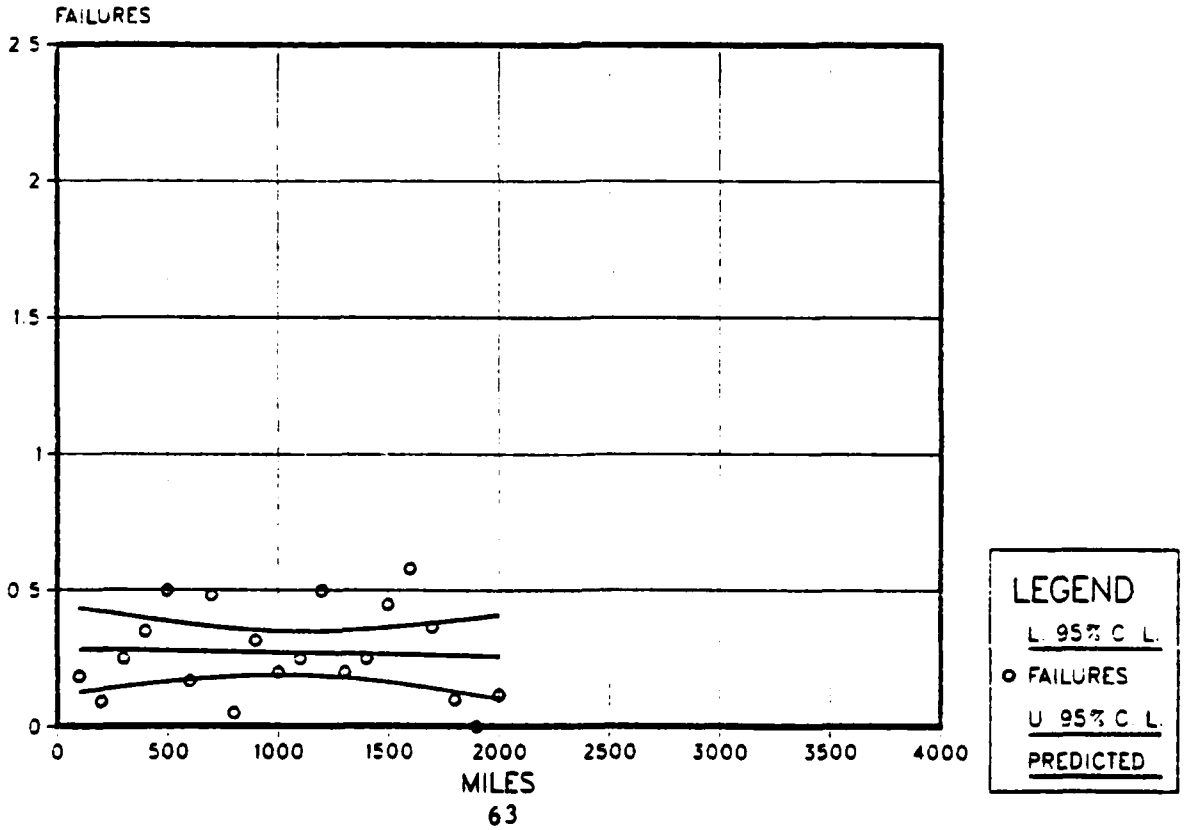

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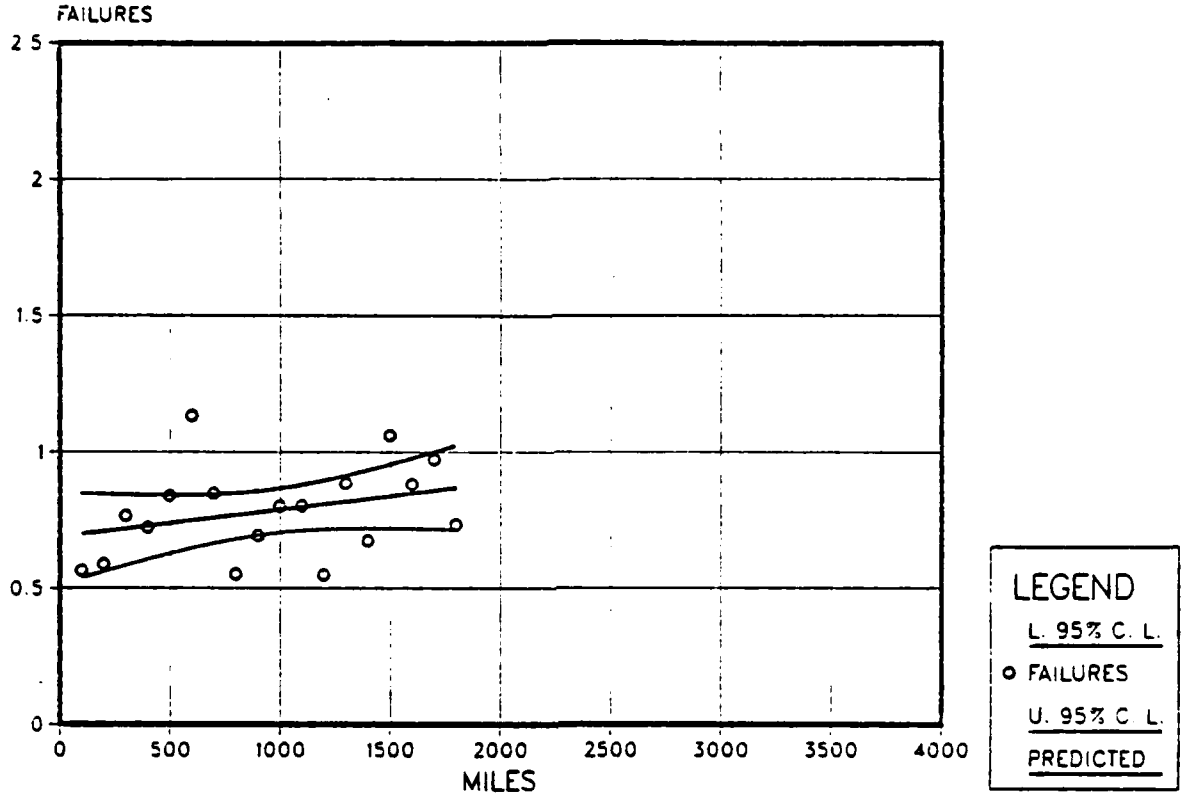

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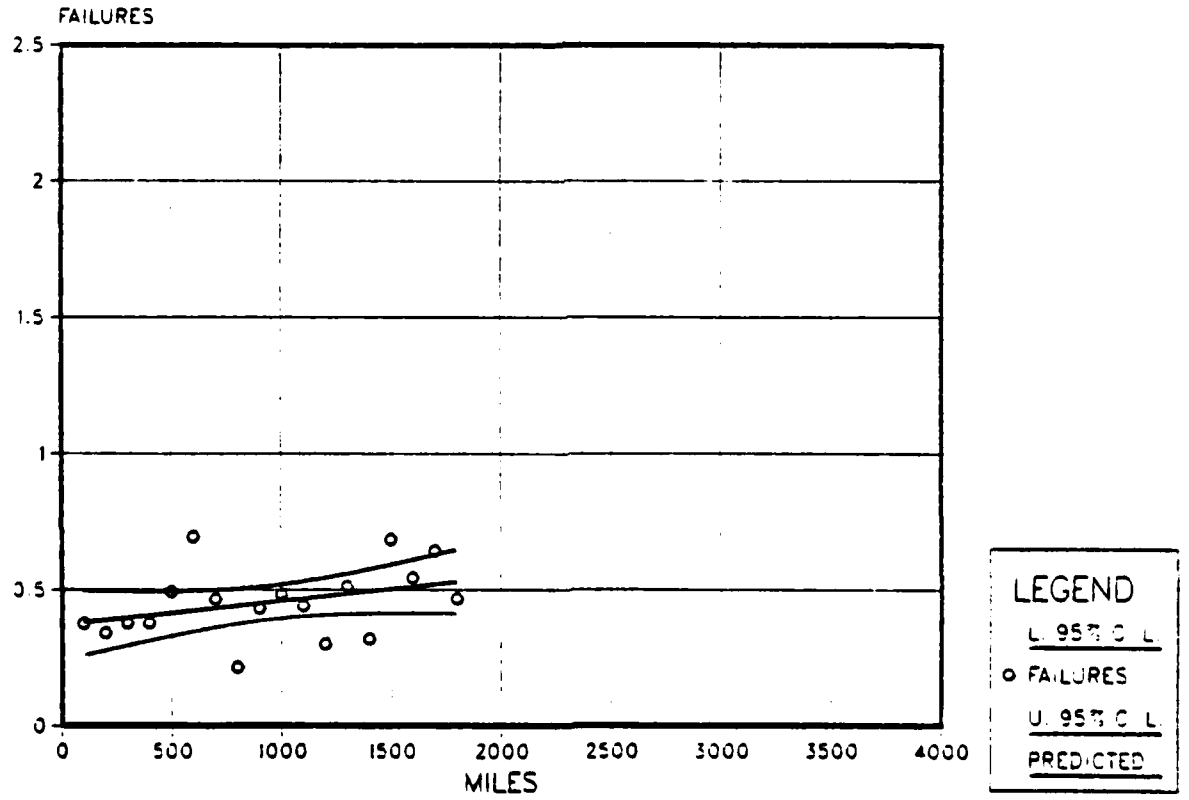

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